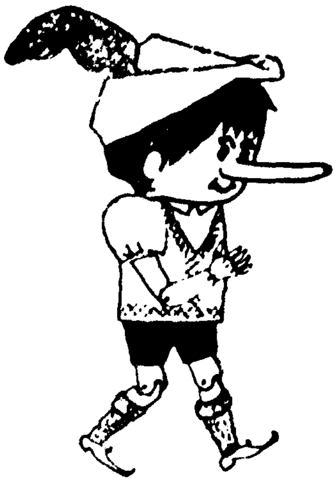
Proceedings of the SYMPOSIUM ON THE EFFECT OF GROWTH ACCELERATION on the PROPERTIES of WOOD



Jointly sponsored by the U.S. Forest Products Laboratory and the API-TAPPI Research Liaison Committee to FPL

Held Nov. 10-11, 1971
Madison, Wis.

FOREST PRODUCTS LABORATORY
FOREST SERVICE
U.S. DEPARTMENT OF AGRICULTURE
1972

The Symposium was jointly sponsored by the Forest Products Laboratory and the industry research liaison committee to FPL from the AMERICAN PULPWOOD INSTITUTE and the TECHNICAL ASSOCIATION OF PULP AND PAPER INDUSTRY

It was held at the Wisconsin Center on the campus of the University of Wisconsin, Madison, Wis.
NOV. 10-11, 1971

A

Proceedings
of Symposium
on the Effect
of GROWTH ACCELERATION
on the Properties of Wood

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FOREWORD

This volume contains papers given and the pertinent discussions at the Symposium on the Effect of Growth Acceleration on Wood Properties, November 10-11, 1971, at Madison, Wis. The symposium was jointly sponsored by the U.S. Forest Products Laboratory and the API-TAPPI Liaison Committee to the Forest Products Laboratory.

The whole question of the effect of growth acceleration has in the past few years assumed new nationwide significance. The stimulus for this renewed interest has its roots in our burgeoning population and their increased demands for wood products. The general public concern about the position of timber in the total resource picture is gradually focusing attention on the attribute that makes wood so unique--a renewable resource in which each succeeding crop can be better than the one previous. There appears little doubt that to meet this challenge future forestry practices must concentrate on growth acceleration.

Specifically, the papers present research results dealing with the effects of growth acceleration--short rotations, tree improvement practices, irrigation, fertilization, and other growth stimulants on the wood and pulp properties of many of the Nation's important commercial woods. From this base, an attempt was made to develop information to lead to a proper balance between maximizing fiber yield and maximizing wood quality.

While the papers as presented by the authors are complete, the tape-recorded panel discussion and the general question and answer sessions did require some editing. Every attempt, however, was made to maintain the essence and continuity of the questions and answers.

The interest and support demonstrated by the representatives from industry, forestry schools, and research laboratories in the area of growth acceleration was encouraging. It is hoped this symposium will accentuate and direct the necessary research to meet the timber demands of the future.

H. E. WAHLGREN
Program Coordinator

Program

for Symposium on

EFFECT OF GROWTH ACCELERATION

ON THE PROPERTIES OF WOOD

Wednesday, November 10

8:00-8:20--Welcome

H. O. Fleischer, Director, Forest Products Laboratory, and Lyle J. Gordon, Chairman, API-TAPPI Research Liaison Committee and Moderator of Symposium

8:20-8:45--Keynote Address

George H. Sheets, Executive V.P., The Mead Corporation, and past chairman of API-TAPPI Liaison Committee

8:45-9:25--Fiber Morphology Considerations in Paper Properties, by Richard Horn, USFS, FPL

9:25-10:05--Influence of Fertilization on Wood and Pulp Properties, by K. Siddiqui, W. Gladstone, and R. Marton, Syracuse University

10:20-10:50--Effect of Irrigation and Fertilization on Wood Quality of Young Slash Pine, by Diana Smith, H. Wahlgren, USFS, FPL, and George W. Bengtson, TVA

10:50-11:35--Effects of Fertilization on Stem, Wood Properties, and Pulping Characteristics of Slash Pine, by J. W. Gooding, III, and W. H. Smith, University of Florida

11:35-12:15--Response in Growth and Wood Properties of American Sycamore to Fertilization and Thinning, by J. R. Saucier and A. F. Ike, USFS, Athens, Ga.

12:15-1:30--Lunch at the Wisconsin Center

1:30-2:10--Detailed DBH Density Profiles of Several Trees From Douglas Fir Fertilizer/Thinning Plots, by R. A. Megraw and W. T. Nearn, Weyerhaeuser Company

2:10-2:50--Patterns of Wood Density Distribution and Growth Rate in Ponderosa Pine, by R. M. Echols, USFS, Berkeley, Calif.

3:05-3:45--Influence of Irrigation and Fertilization on Growth and Wood Properties of Quaking Aspen, by Dean W. Einspahr, Miles K. Benson, and Marianne L. Harder, Institute of Paper Chemistry, Appleton, Wis.

3:45-4:25--Effect of Nitrogen Fertilizer on Growth Rate and Certain Wood Quality Characteristics of Saw'og Size Red Oak, Yellow-Poplar, and White Ash, by H. L. Mitchell, USFS, FPL

4:25-5:10--Related Aspects of the Morphology of Loblolly Pine and Papermaking, by A. C. Barefoot, R. G. Hitchings, E. H. Wilson, and R. C. Kellison, North Carolina State University, Raleigh, N.C.

7:00--Banquet in the Wisconsin Center

Thursday, November 11

8:00-8:35--Volumes, Wood Properties, and Fiber Dimensions of Fast- and Slow-Grown Spruce Pine, by F. G. Manwiller, USFS, Pineville, La.

8:35-9:05--Wood Properties of Young Loblolly and Slash Pines, by Bruce Zobel, R. C. Kellison, North Carolina State University, Raleigh, N.C., and D. G. Kirk, Hammermill Paper Company, Erie, Pa.

9:05-9:35--The Three-Rings-Per-Inch Dense Southern Pine--Should It Be Developed?, by Peter Koch, USFS, Pineville, La.

9:50-10:25--Summary of Symposium, by C. Ostrom, USFS, Washington, D.C.

10:25-12:00--Panel Discussion, "Impact of Accelerated Growth to the Pulp and Paper Maker--Conclusions" (panel members: W. M. Hearon, Boise Cascade Papers; W. P. Lawrence, U.S. Plywood-Champion Papers; H. L. Mitchell, USFS, FPL; J. P. van Buijtenen, Texas Forest Service; R. Zahner, University of Michigan; B. Zobel, North Carolina State University).

Adjourn

WELCOME

H. O. FLEISCHER
Director, FPL

Good morning to all of you who have come to participate in this Symposium on the Effects of Growth Acceleration on Wood. One of the nice things at the Forest Products Laboratory is our good relations with people in the industry, particularly in the area that is represented and is going to be discussed here this morning. We have the good fortune to have the API-TAPPI Liaison Committee meet with us at the Laboratory once a year to review our research program especially in the area of pulp and paper, and advise us on the needs and wishes of the industry in the way of research. A year or more ago this committee began asking whether we could put together available information on accelerating growth of trees and the effect of such forestry practices on the properties and the utility of the wood produced. Naturally the emphasis is on pulp and paper properties but I don't think it is necessarily limited to that. We responded to that request and, with the aid of the API-TAPPI Committee, the result is the program that will be presented to you here now.

I now have the privilege of introducing the chairman of this meeting who also happens to be chairman of our API-TAPPI Liaison Committee.

Dr. Lyle Gordon is corporate manager of pulping research and development work of the Scott Paper Company and they tell me he commutes between Everett, Wash., and Philadelphia, Pa., to perform his function. He is president of TAPPI at the present time and is a chemical engineer with a Ph. D. from the University of Washington. We know from our past dealings with Dr. Gordon that he is eminently qualified to serve as discussion leader and chairman of this symposium. And so as I turn this meeting over to you, Dr. Gordon, I wish all of us success in learning and bringing out at this meeting the available information on this subject. We hope to identify the gaps in our information, the lack of knowledge and, perhaps based on that, to redirect our research to fill those gaps. Dr. Gordon.

SYMPOSIUM CHAIRMAN'S REMARKS

LYLE GORDON
Corporate Manager, Pulping R&D,
Scott Paper Company

Thank you very much. I'd like to add to the welcome that has already been given to you. The wisdom of the committee in selecting this as an important and timely subject is brought out by the fact that all of you, too, have felt that this is a subject worthy of your attention.

It is my real privilege this morning to introduce our keynote speaker. He began his career with the Mead Corporation in 1941, as a development engineer in the research department at Chillicothe, Ohio. For the next 12 years, he held various assignments at Chillicothe including manager of corporation technical service, staff assistant to the executive vice-president, and assistant to the Chillicothe division manager. In April of 1962, he was elected vice-president of the Corporation by the board of directors and in September of the same year, was elevated to group vice-president for white papers. When the Mead Corporation adopted the concept of the president's office in 1968, he was elected executive vice-president. He holds a degree in chemical engineering from Ohio State University and a Ph. D. from the Institute of Paper Chemistry. He is the immediate past president of TAPPI and former chairman of this Liaison Committee. It is a real privilege for me to introduce the keynote speaker, Dr. George Sheets.

KEYNOTE ADDRESS

by

GEORGE H. SHEETS

Executive Vice President
The Mead Corporation
Dayton, Ohio

While I'm not up to a "keynote address" on the effect of growth acceleration on wood properties there are some "notes" which seem to me of key significance:

First is a personal note of congratulations to the Forest Products Laboratory and its scientists and technicians for a record of past accomplishment and excellent cooperation with industry.

Those of us in the pulp and paper business have long appreciated the type of fundamental research carried on by this Laboratory. Such research is especially needed. Too often industry tends to lean toward applied research in its desire for quick, commercial results. But we need more inputs of basic scientific knowledge.

Real economic and social progress can come from careful, scientific probes into relevant questions such as the ones we are considering today. So, I would like to also commend the API-TAPPI Liaison Committee for bringing together members of the Lab, universities, industry, their technical people, members of the Department of Agriculture, and the U.S. Forest Service for this technical overview of a very basic question.

Another note of significance to me is the perspective of our meeting: Why is the subject of growth acceleration and its effect on wood properties so vital to us in business, to you in Government, and to the Nation?

At the heart of the matter, obviously, is our mutual concern to meet the Nation's future needs for wood. Three factors make this concern critical: A shrinking land base for growing wood, an increasing population, and a growing demand for wood products.

We cannot take comfort from reports that we are still growing about as much wood each year as we consume. That may be good enough for today but not for tomorrow.

The current estimate is that the United States has about 2.5 acres of commercial forest per capita. Through population growth alone the per capita figure will drop to 1.9 acres by the year 2000.

But the 1.9-acre figure does not take into account further shrinkage of our commerical forest land base. I understand from the latest U.S. Forest Service statistics that this year the land base for our commercial forest has shrunk for the first time since the Service started making periodic surveys.

Government figures show that by the year 2000 we will need twice the present volume of wood products; yet we will also need twice as much land for homes, schools, factories, and other urban uses; 8 million more acres of land for reservoirs; 5 million more acres for wildlife refuges; and 4 million for transportation.

If we look at market demands--for paper and shelter--the national need for more wood comes into even clear focus. Presently the per capita consumption of paper in our country is between 500 and 575 pounds. By the year 2000 the estimate shoots up to 1,000 pounds per person. Timber requirements, based on housing projections, vary but the high figure for the year 2000 is about 26 billion cubic feet--attainable, but only if forestry practices are introduced or improved on more land.

As I indicated earlier we are not going to have more commercial forest land. The prospect is for less. Clearly, we are at a crossroad! A quick and obvious answer would be to grow more wood, faster, on the same or shrinking land base! But how to do that economically and what effect such an acceleration will have on wood properties is the "meat" of this symposium.

Most of us are aware that with the help of Government agencies represented here, the forest products industry has had some past success with intensive forest management. Through genetics, site preparation, and scientific harvesting we've been able to grow more timber than is harvested on industry-owned lands.

But less than half of the U.S. commercial forest land is well managed. Thirteen percent of the total is controlled by the forest products industry; 22% by Federal, and 6% by State Governments. The remaining 59% is privately owned and most of it is very poorly managed. Much can be done by educating private owners about forest management and fertilization.

One of the success stories is the South. In 1935 forest lands in the 12 southern states contained 120 billion cubic feet of wood. In 1970 these same lands contained 141 billion cubic feet--up 21 billion in 35 years. During the same period 169 billion cubic feet of wood were harvested from the South's forests.

As for the South's future growth of wood there is a dramatic concept calling for "A Third Forest" which in the year 2000 will be growing trees on 10 million less acres but, nevertheless, will have to produce twice as much wood as the 1968 harvest. The South's past success and this future challenge dramatizes the national pressure for accelerated growth.

Unfortunately, in terms of large-scale forest fertilization and growth acceleration we are really just getting started in the United States. We need more information and more experience. Compared to the experience of European managers of forest land we are babes in the woods.

The Swedish Cellulose Company with 5 million acres of forest land was the first company, to my knowledge, to employ fertilization on a large commercial scale. Beginning in 1957, it was almost 10 years and thousands of sample plots later before they had sufficient information to justify large-scale applications of urea which is now applied on 150,000 acres annually.

Almost 20 years have passed since a group of landowners began studying forest soils in the Pacific Northwest. This group of cooperating companies (Northwest Forest Soils Council) continues to learn more about inexpensive methods to diagnose nutrient deficiencies in the soil and the growth response to various treatments. In the Northwest, as in Sweden, increased growth response of as high as 40% has been reported.

My own company, through its affiliates, participates in cooperative efforts which I am sure will be discussed here todav or tomorrow:

One is the University of Florida's Cooperative Research in Forest Fertilization (CRIFF) formed in 1967. This program, I understand, is a combined effort of the major forest landowners in the lower Coastal Plain area of the Southeast. Brunswick Pulp and Paper participates in this program as well as the Hardwood Research Program sponsored by the School of Forest Resources of North Carolina State University.

Another program--one in which another affiliate, Georgia Kraft Company, is associated--is called the North Carolina State Forest Fertilization Cooperative. Begun a year or two ago, this group effort concentrates on soils in the Piedmont and northern Coastal Plain region of southeastern United States. The group has indicated that the economic feasibility of forest fertilization requires more investigation and facts about the influence of fertilization on <u>wood properties</u> as well as dry weight yields, increases in wood volume, and other miscellaneous factors.

These and a number of other new programs illustrate the awakening in our industry and in our country of the real need for more research and advances in forest technology--especially if we are going to grow future wood requirements on a shrinking land base.

In advancing forest technology we have to consider, for example, how the programs for tree improvement through genetics can be wedded to efforts toward accelerated growth. And there are many, many other questions for which we need answers based on hard data. For example, what is the best and most economical method of fertilization for the myriad of soil conditions and tree species that exist? And, how can we increase productivity so that we get not only greater volume but maintain or enhance valued wood properties?

When growth is accelerated we need to know what happens to the individual fiber structure. Do the fiber walls become thinner or do they become thicker? This is of great interest to the papermaker. One of the drawbacks of southern pine is its relatively large content of summerwood fibers, which make it unsuitable for the manufacture of certain types of papers. Another question--Does growth acceleration change the chemical makeup of wood? Does it lead to a higher or lower lignin content, or a higher or lower cellulose content? This is of great economic importance to the pulp producer. After all--the goal from a pulp maker's view must be to obtain as high a pulp yield as possible from a given acre of land. Many many more such questions can be posed.

In conclusion, it seems to me we are entering a new era of forest management that can have as great an impact on our economy and national well being as the control of inflation. Certainly when you come to a crossroad and face a frontier you need all the information you can obtain. That, to me, is <u>the</u> keynote of this symposium.

* * *

<u>Gordon</u>--Thank you, George. Certainly all of us are aware of many of the factors that are involved in the acceleration of growth with the resulting impact on fiber and on wood. Many of these things we are doing are competing things. I think many times, when people say they would like to increase yield, what they're really saying is that they would like to increase yield of the best fibers they've had before. So they mean, "Give us more of these." And certainly as we endeavor to do this, there are competing factors. These are not always working in the same direction; frequently, in fact they are opposed.

FIBER MORPHOLOGY CONSIDERATIONS IN PAPER PROPERTIES

by

R. A. HORN[1]

Extended Abstract

The influence of fiber morphology on the papermaking characteristics of fibers from 12 western U.S. softwood species is currently being investigated. Emphasis is placed on the effect of pulp fiber morphology rather than the conventional wood-to-pulp fiber relationships. This information is not being sought so much for effects within a particular species but rather for the wide range of fiber types available from the various wood species.

The pulpwood samples were obtained by random selection from growth ranges in the western United States. Specifications for each species dictated that the bolt be 5 feet in length, have a diameter of 8 to 12 inches breast height, each 5-foot bolt be cut from the 5- to 10-foot interval (based on ground level), and that the wood be free of compression wood. Two samples were collected for each species from different sites. The bolts were debarked and chipped, during which a composite sample was prepared for each of the species.

All species were pulped by the kraft process. For comparison purposes each species was cooked to a kappa range of 30 to 33. No serious problems were encountered replicating individual cooks to the desired kappa numbers.

Morphological measurements of pulp fiber and certain physical properties of pulp handsheets were made on all species (table 1). Morphological measurements on the pulp fibers included fiber length, fiber coarseness, number of fibers per gram, cell wall thickness, fibril angle, and cross-sectional area. All handsheets were prepared according to TAPPI standard procedures.

The following results and discussion constitutes only the preliminary analysis of the data and concerns only unbeaten pulp fibers.

It is generally accepted by many that fiber length is closely correlated with pulp strength properties, especially tear. However, in this study no relationship was observed between fiber length, per se, and any measured sheet property.

Fibril angle did not have any observable influence on sheet strength properties. There was, however, a correlation between fibril angle and stretch of the pulp sheets (fig. 1). This observation supports the contention that the fiber's internal structure has an influence on the extensibility of paper. Some attribute stretch in paper to a movement between fibers. However, it is evident that the fiber does contribute, depending on fibrillar angle, to the extensibility of paper.

[1]Forest products technologist, Forest Products Laboratory, Forest Service, U.S. Department of Agriculture.

Table 1.--Influence of fiber morphological characteristics on the pulp sheet physical properties made from unbeaten, unbleached kraft pulp

Species	Morphological properties								Stretch	Burst factor	Tear factor	Tensile strength	Modulus of elasticity	Sheet density	Bulk
	Wood density[1]	Fiber length[2]	Cell wall thickness[3]	Fibril angle[4]	Cross sectional area	Length/thickness (L/T)	Pulp fiber coarseness[5]	Fibers/gram[6]	Fibers/cubic centimeter						
	G./cm.^{3}	Mm.	μ	°	μ^2		Mg./100 m.	10^5	10^5	Pct.			P.s.i.	1000 P.s.i.	G./cm.^{3}	Cm.^{3}/g.
Lodgepole pine	0.426	3.45	3.02	4.5	181	1142	23.1	14.65	8.64	1.96	57	138	6700	822	0.59	1.69
Western larch	.527	3.96	3.87	5.9	250	1020	32.5	8.65	4.50	1.76	27	163	3560	487	.52	1.92
Douglas-fir	.458	3.50	3.41	6.3	220	1040	30.8	9.51	5.52	2.19	36	188	4640	599	.58	1.72
Western white pine	.383	3.40	2.88	7.0	148	1170	24.1	13.13	8.66	2.50	64	119	8150	875	.66	1.52
Port Orford cedar	.367	2.98	2.12	8.5	110	1406	15.0	23.08	15.23	2.63	75	179	9700	910	.66	1.52
Alaskan yellow cedar	.373	2.67	2.13	9.0	98	1254	15.8	22.06	15.00	2.66	70	150	8580	1061	.68	1.47
Grand fir	.390	3.33	3.23	9.5	147	1030	24.3	13.70	8.22	2.55	55	155	6490	766	.60	1.67
Western hemlock	.449	3.39	3.23	10.9	202	1050	29.0	10.52	6.52	2.59	53	178	6520	805	.62	1.61
Sitka spruce	.341	3.19	2.87	11.7	131	1111	21.7	15.90	10.34	[illegible]	58	176	7090	771	.65	1.34
Western red cedar	.312	2.95	2.00	11.8	100	1475	15.4	22.56	15.79	2.83	84	146	10800	900	.70	1.43
Ponderosa pine	.406	3.65	[illegible].38	16.0	190	1080	26.0	12.45	7.85	2.94	60	167	688[illegible]	753	.63	1.59
Redwood	.406	3.98	3.10	21.5	173	1285	26.8	11.90	7.62	2.95	68	165	7640	870	.64	1.56

[1]Based on weight when ovendry and green volume.

[2]Based on measurement of 50 whole, unbeaten pulp fibers.

[3]Average of 4 measurements per fiber of 35 fibers.

[4]Method from Page (3).

[5]Method from Britt (1).

[6]Method from Horn (2).

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Forest Service
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Madison, Wisconsin 53705

It is clear from this study that wood density is an important factor. In these softwood species, with the exception of tearing strength, pulp quality (modulus of elasticity, burst, tensile) was adversely affected beyond a wood density of 0.450 gram per cubic centimeter. Admittedly, there were only two species with greater density values, but the decrease in strength qualities was marked (table 1). As previously shown by others, cell wall thickness of the pulp fiber was related to original wood density (fig. 2). Also, it was found that cell wall thickness correlated with number of fibers per gram of pulp (fig. 3).

The combined effects of cell wall thickness and fiber length on pulp quality can be seen in figures 4, 5, and 6. Most commonly the ratio of length to fiber diameter is used as a guide to pulp quality. However, we suggest a more meaningful correlation would appear to be the ratio of pulp fiber length to cell wall thickness (L/T). This ratio would seem to provide an index to the "flexibility" of the fibers involved. Though other factors may be involved, in particular the chemical composition of the fiber, there is evidence to suggest that the L/T ratio of pulp fibers has a considerable influence on the papermaking characteristics of fibers. That is, a high L/T gives high tensile strength and modulus of elasticity. Notwithstanding the effect that beating and other process variables have on promoting sheet strength, it appears that the tensile strength of paper is greatly affected by the original fiber characteristics.

This is clearly shown in figures 7 and 8. These graphs show that strength was increased by beating, but the shape and the relative position of the species on the curve was the same as that of the unbeaten fiber. This in effect says that woodpulp fiber with desirable morphological characteristics will give good strength properties in paper regardless of conversion variables.

The observations that cell wall thickness correlates closely with number of fibers per gram (fiber weight), and that L/T has a considerable influence on sheet strength properties, suggested that sheet strength should be greatly dependent upon the number of fibers per unit volume of sheet. Figure 7 shows that this is indeed the case. The effect that original wood density has on the number of fibers per unit volume of a pulp sheet is clearly shown in figure 8. Therefore, it too must be considered as an important morphological factor influencing pulp quality.

Further analysis of data obtained in this study is expected to better our understanding of the fiber morphology-pulp sheet relationships.

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1966. FIBER COARSENESS IN WOOD. Tappi 49(5): 202-206.

(2) Horn, R. A.
1970. RAPID DETERMINATION OF THE NUMBER OF FIBERS PER GRAM OF PULP. Tappi 53(11): 2120-2122.

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1969. A METHOD FOR DETERMINING FIBRIL ANGLE IN WOOD TRACHEIDS. J. of Microscopy 90: 137-143.

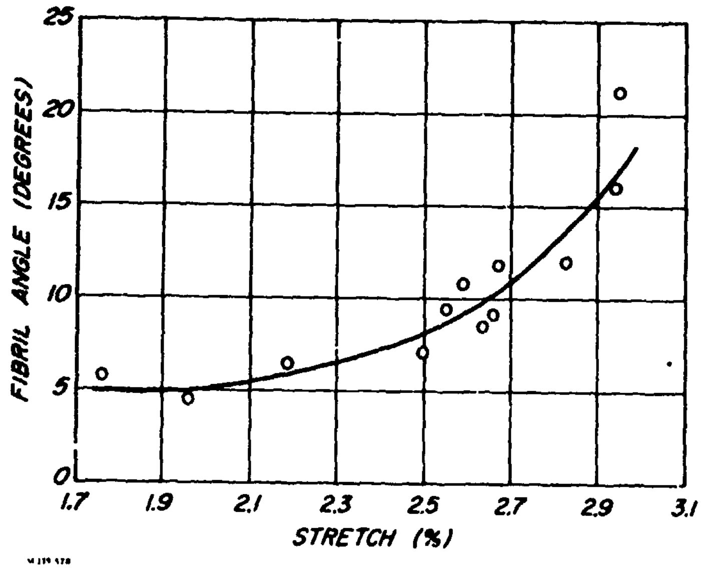

Figure 1.--Stretch-fibril angle relationship of handsheets made from unbeaten, unbleached kraft pulps from 12 western U.S. softwood species.

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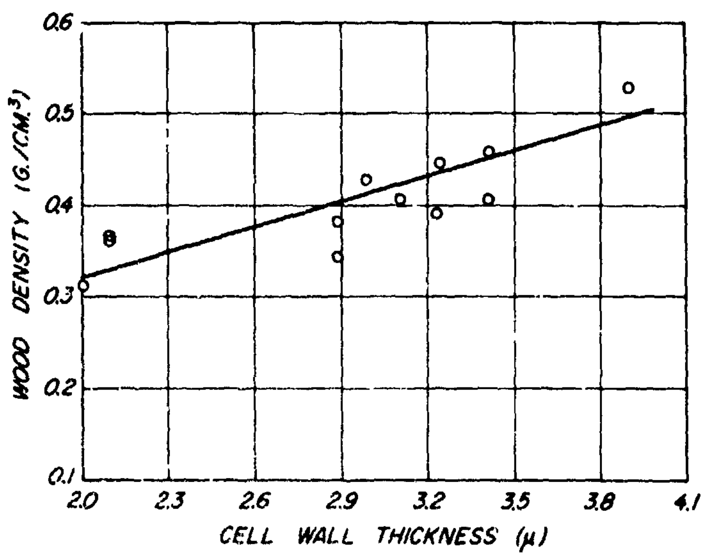

Figure 2.--Cell wall thickness of unbeaten, unbleached kraft pulp fibers from 12 western U.S. softwood species related to original wood density.

(M 139 58?)

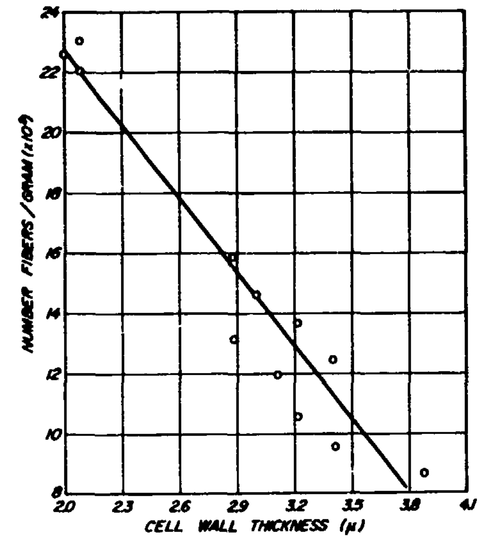

Figure 3.--Number of fibers per gram related to cell wall thickness of unbeaten, unbleached kraft pulp fibers from 12 western U.S. softwood species.

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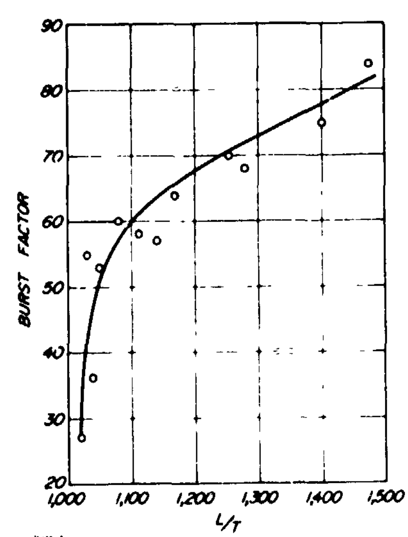

Figure 4.--Influence of L/T ratio on bursting strength for handsheets made from unbeaten, unbleached kraft pulps from 12 western U.S. softwood species.

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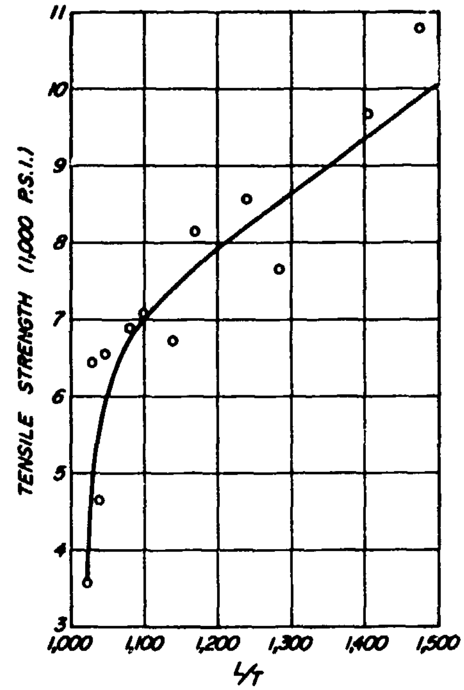

Figure 5.--Influence of L/T ratio on tensile strength for handsheets made from unbeaten, unbleached kraft pulps from 12 western U.S. softwood species.

(M 139 580)

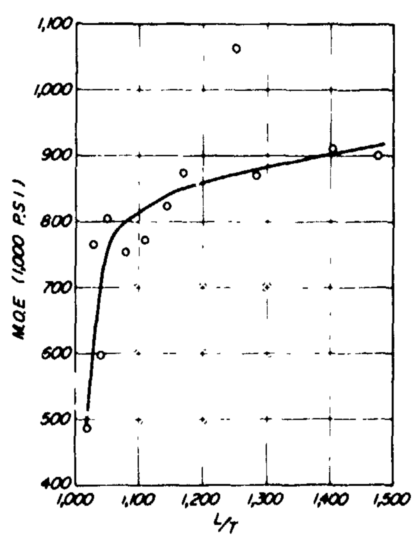

Figure 6.--Influence of L/T ratio on modulus of elasticity for handsheets made from unbeaten, unbleached kraft pulps from 12 western U.S. softwood species.

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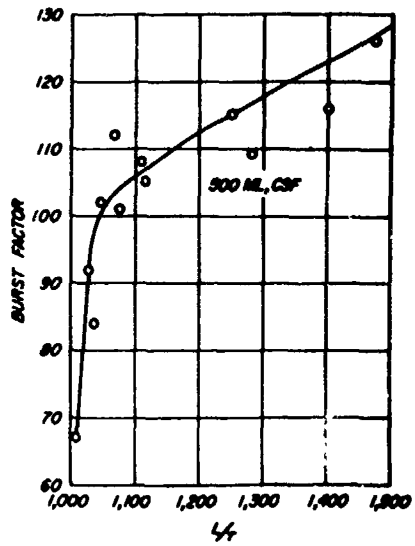

Figure 7.--Influence of L/T ratio on bursting strength for handsheets made from beaten, unbleached kraft pulps from 12 western U.S. softwood species.

(M 139 692)

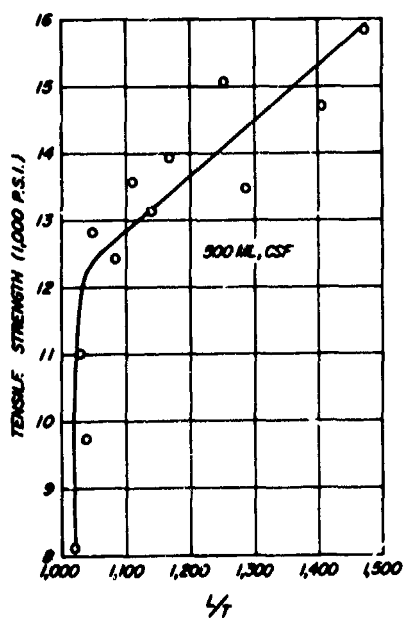

Figure 8.--Influence of L/T ratio on tensile strength for handsheets made from beaten, unbleached kraft pulps from 12 western U.S. softwood species.

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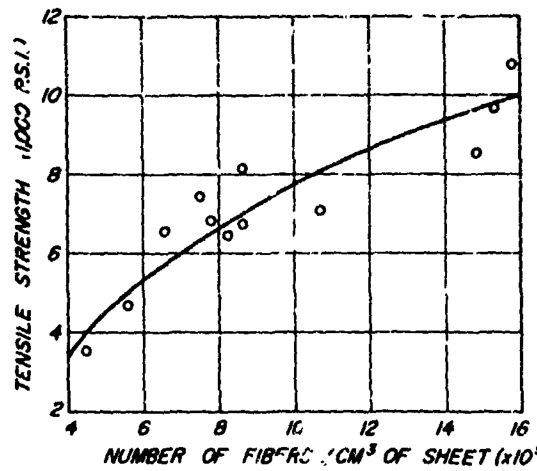

Figure 9.--Dependence of sheet tensile strength on number of fibers per unit volume of sheet. Unbeaten, unbleached kraft pulp from 12 western U.S. softwood species.

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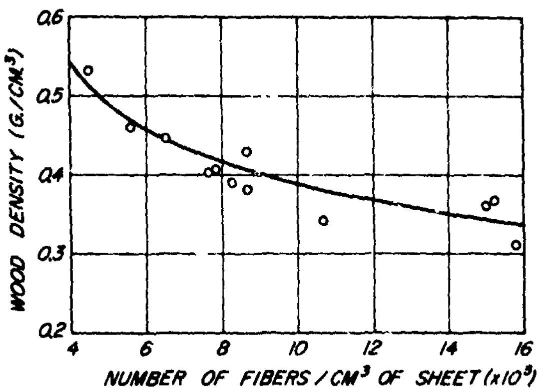

Figure 10.--Number of unbeaten, unbleached kraft pulp fibers per unit volume of sheet related to original wood density of the 12 western U.S. softwood species.

(M 139 585)

* * *

Gordon--The first question is, does the L/T ratio change as the fiber is beaten?

Horn--I can't say positively because we haven't looked into the data for the beaten pulp that extensively. We are now doing so. But it did show the same relationship for bursting and tensile strength for the pulps beaten to 500 Canadian Standard Freeness.

Gordon--As a part of that question, what method did you use for beating to the 500 Canadian Standard Freeness?

Horn--Valley beater was used.

Gordon [paraphrasing audience question]--Would you define basic wood density for us, please?

Horn--Basic wood density as I use it is based on weight of wood, ovendry and green volume.

Question--How did you measure fibril angle? Do you consider this a composite of the cell wall or the secondary wall only?

Horn--We used the method developed by D. H. Page. It employs vertical polarized illumination and is a very easy method to use. Because 80% to 95% of the cell wall material is contained within the middle secondary layer (S_2), for practical purposes the method gives an average fibril angle for this layer.

Question--With regard to the validity or variation of the L/T ratio within a species, are you considering various ages within a species?

Horn--No. We're interested in trying to get a handle on fiber morphology and what morphological factors most influence paper properties. At this point we feel more practical information can be obtained for differences between species rather than for one species.

Question--What did you use to determine the age of the trees that would be examined or wood that would be examined?

Horn--This was strictly on a random selection basis; there was no predetermination of age class at all. As I stated, the requirements were that it be randomly selected, the bolt be 5 feet in length, have a diameter of 8 to 12 inches breast height, be cut from the 5 to 10 foot interval, and that it be free of compression wood.

Lowery, Forest Service--What was the difference between sites? Any selection basis or just a random selection?

Horn--Just a random selection.

Lowery--It could be then from the same or similar sites, is that right?

Horn--Could be.

Kellogg, Canadian FPL--The relationship that you have shown in the number of fibers per gram and strength properties supports the idea of the importance of fiber coarseness. It seems to me that the relationship of strength properties to the L/T ratio seems to deny that. If the thickness is the same for a given length and the diameter of the fiber changes, the coarseness is going to change. And yet you have very little variability in strength. On the other hand, you showed a good relationship between number of fibers per cubic centimeter per sheet. It seems to me that would be closely related to coarseness of the fiber. I can't put the two together.

Horn--You're right in that coarseness is important and that coarseness will change depending upon thickness and diameter. However, I feel that L/T is a better indicator for assessing strength qualities because it takes into account the change in fiber length as well as thickness. As to showing little variability in strength, I don't think this is so if you look at the figures. I can't answer positively but, I think if L/T were plotted against number of fibers per unit volume, a relationship would exist. In effect, a high mass of fiberous material per unit volume dictates that the fiber be thin walled and low in coarseness. Therefore, I think that L/T and coarseness would show some sort of relationship. However, the variation in strength of the pulps cannot be accounted for by coarseness per se. It's my feeling that the length to thickness ratio more fully incorporates the important fiber properties in regard to paper strength. This can be shown by ranking the species according to all strength properties and comparing this with their ranking in respect to L/T.

Nichols, Institute of Paper Chemistry--In the case of softwoods, could you use the extractive-free wood density as an alternative to wall thickness?

Horn--I don't know that I have enough experience in that to answer that question. I'm sure that there are possibly others here that could.

Gordon--Speaking specifically to this question, relative to the extraction of the wood and getting the extractive-free density and comparing that with cell wall. Anyone here want to comment on that?

?????--For most of the species on this table, it doesn't make that much difference. The only one that this really gets into a problem with is southern pine and that isn't included. Our experience is that extractive-free density versus the unextracted density is of so little consequence that the same relationships hold.

Setterholm, FPL--Of the three criteria you've talked about for assessing pulp quality--number of fibers per gram, wood density, and L/T--how would you rank these as to their value in assessing pulp quality?

Horn--Certainly L/T would be the best indicator. Density can be used as a general indicator, but the other two are much more specific toward indicating pulp quality in regard to strength.

van Buijtenen, Texas Forest Service--How can you tell what is important and what's not important and what are the alternative approaches for determining this experimentally?

Gordon--I dare say each of us may have been faced with that a time or two in our lives and perhaps as recently as yesterday. Unfortunately for Horn, he is here.

Horn--I don't really know how to answer that question. Perhaps part of it is the feeling you develop as you work with a thing for a while about what is important and what is not. You check and recheck the data and the results. If something is related you have a feeling that you know why there is a relationship. Length to thickness ratio to me only makes sense. This is important from the standpoint of conformability characteristics of pulp fibers which reflects then the fiber bonding capacities of such pulp fibers. I realize that this is a very poor answer to the question.

Sheets--I'd like to comment from a practical papermaking point of view. This L/T is quite important, especially in the manufacture of thin papers; if you have twice as many fibers per area, you don't have as many pinholes. By the same token if you're making a sheet of raw stock and you have a lot of summerwood fiber, this causes an uneven surface and you get little pits which are very difficult to cover up in the coating operation. So these factors are extremely important from a practical papermaking point of view.

Gordon [paraphrasing]--Have you done any work on hardwood fibers?

Horn--Not yet, but we intend to.

INFLUENCE OF FERTILIZATION ON WOOD AND PULP PROPERTIES OF DOUGLAS-FIR

by

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Abstract

Fertilization of Douglas-fir with urea resulted in a 74% increase in volume growth accompanied by a 10% decrease in wood specific gravity. The impact of this decrease on weight-based productivity, however, was halved by a substantial increase in pulp yield per unit weight of wood. The increased pulp yield from fertilized wood is attributed to a decrease in extractives and an increase in the proportion of S_2 wall layer in earlywood tracheids. A small decrease in percent latewood and a reduction of wall thickness in latewood are probably responsible for the lower specific gravity of fertilized wood.

Introduction

Increasing interest in artificial fertilization as a silvicultural tool to increase forest productivity has awakened a parallel interest in the properties of wood produced under fertilizer regimes. In recent years, the standard measurements of height, diameter, and volume growth responses have often been supplemented with an examination of simple-to-measure but otherwise complex wood and fiber characteristics, including specific gravity, percent latewood, and fiber length. Many early reports indicated a reduction in percent latewood and specific gravity following moderate to heavy fertilization (Erickson and Lambert, 1958; Zobel et al., 1961; Posey, 1964), though these properties are not always altered by fertilization (Tamm et al., 1960).

The appraisal of many apparent inconsistencies led Klem (1968), in an excellent review of fertilization and wood quality, to conclude that the results of a fertilization treatment on wood characteristics to a great extent depend upon the condition of the tree before treatment. When variation in species response, in fertilization treatment, in sampling procedures, and many other factors are superimposed on preconditioning, it is obvious that a variety of responses will be detected. Generalizations will be difficult and much specific information will be necessary for successful applications of the fertilizer tool.

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A few detailed analyses of fertilized wood as a raw material have included chemical and pulping characteristics. Erickson and Lambert (1958) reported a tendency for extractives to increase and holocellulose to decrease with fertilization of Douglas-fir. Both trends would reduce pulp yield. Zobel et al. (1961) found a similar decline in loblolly pine holocellulose attributable to fertilization. Pulp yields in the studies of Jensen et al. (1967) and Hagner (1967) were unaffected by the fertilization of pine and spruce. Pulp quality in the latter study alone reflected changes due to fertilization, the burst and tensile factors increasing and the tear factor decreasing under treatment.

The effects of urea fertilization on the growth and the pulping properties of Douglas-fir wood are reported in the balance of this paper.

Experimental

Sample History

The wood samples for this study were supplied by Crown Zellerbach Corporation from a naturally regenerated study of Douglas-fir in western Washington. In December of 1969, four dominant or codominant trees were selected from within (fertilized) and four from just outside (controls) a study plot which had been treated with 400 pounds per acre of nitrogen in the form of urea in April 1963. The trees ranged in age from 45 to 52 years at the time of felling. A sample bolt which retained 31 growth increments from pith to cambium was cut from each tree.

Pulping

The outer seven growth rings, formed after fertilization, were separated from the sample bolts and chipped by hand for kraft pulping. Two 50-gram chip charges, one each from a fertilized and a control tree, were pulped simultaneously in a single microdigester under the following conditions:

Active alkali	21.5% as Na_2O, ovendry wood basis
Sulfidity	25.0% of active alkali
Maximum temperature	173° C.
Time to maximum temperature	60 min.
Time at maximum temperature	90 min.

Four such cooks produced four fertilized-unfertilized pulp pairs. Handsheets were prepared and tested according to TAPPI Standard Methods T205m-58 and T236m-60, respectively. A series of cooks utilizing chips which represented the entire cross section of each sample bolt was included to supplement the yield data.

Wood and Tracheid Properties

The examination of wood and tracheid properties was restricted to the outer seven ring increment of each tree. Wood specific gravity was measured on appropriate radial wedges using the maximum moisture content method (Smith, 1954). Percent latewood was estimated by examining transverse sections at 30X magnification and represents a linear proportion as measured across a 7-year increment. Alcohol-benezene extractives were run on within-tree composites of earlywood and of latewood after radial wedges had been segregated into these components and milled.

The earlywood and latewood fractions of the fourth annual ring from the cambium were studied in detail in an effort to further define the character of the fertilized and unfertilized woods. The number of cells in radial file in each component was obtained from the transverse sections prepared for percent latewood estimation. Tracheid width and length were measured on macerated material, the former by microprojection at 20X and the latter at 400X using a microscope fitted with a split-image eyepiece.

Small blocks of wood representative of the fourth ring were embedded in epoxy resin for ultrathin sectioning (Luft, 1961). Polymerized blocks were sectioned transversely at 800 to 1,200 Å and the sections mounted on 100 mesh, carbon-coated, copper grids. The embedding material was then removed from the sections (Mayor et al., 1961) and the sections were shadowed with germanium. Photographic images produced by an RCA EMU-3 electron microscope were enlarged three to four times and traced on paper. The widths and proportional areas of the cell wall components, i.e. compound middle lamella, S_1 layer, S_2 layer, and S_3 layer, were then measured from the tracings. Examples of photographs from which these measurements were developed are presented in figure 1.

Results and Discussion

Growth Response

Growth data obtained from stem analyses of the sample fertilized and control trees are summarized in table 1. The ratio of the average volume growth during the 7 years after fertilization to that of the 7 years prior to fertilization was calculated to be 1.59 for the fertilized trees while the corresponding ratio for control trees was 1.02 Field mensurational data collected 6 years after fertilization (1968) established that the trees on fertilized plots exceeded those on control plots in volume growth by 74% during those 6 years. The sample trees included in this analysis thus exhibit a conservative and, on examination of the growth ratios in table 1, a consistent response to the fertilization treatment.

Significant diameter growth responses are indicated in figure 2, which presents diameter growth data in the form of a finite difference curve (Kawana et al., 1969). It is apparent from this curve that the response to fertilization continued for several years after the application.

Table 1.--Growth data from sample trees[1]

Tree	DBH	Age	Height	Periodic volume growth 1955-62	Periodic volume growth 1962-69	Growth 1962-69 / Growth 1955-62
	In.	Yr.	Ft.	Cu. ft.	Cu. ft.	
Control 1	9.2	45	72.6	2.69	2.37	0.881
Control 2	9.8	46	72.9	3.37	3.83	1.136
Control 3	13.7	46	82.4	5.19	4.10	.789
Control 4	14.2	45	88.4	10.01	11.47	1.145
Mean	11.7	46	79.1	5.33	5.44	1.02
Fertilized 1	13.4	48	91.0	6.35	9.64	1.518
Fertilized 2	10.0	50	78.2	3.39	6.39	1.884
Fertilized 3	13.0	52	91.8	6.44	9.96	1.546
Fertilized 4	9.5	46	80.9	3.28	5.08	1.548
Mean	11.5	49	85.5	4.87	7.76	1.59

[1]Stem analysis data supplied by Crown Zellerbach Corporation, Camas, Wash.

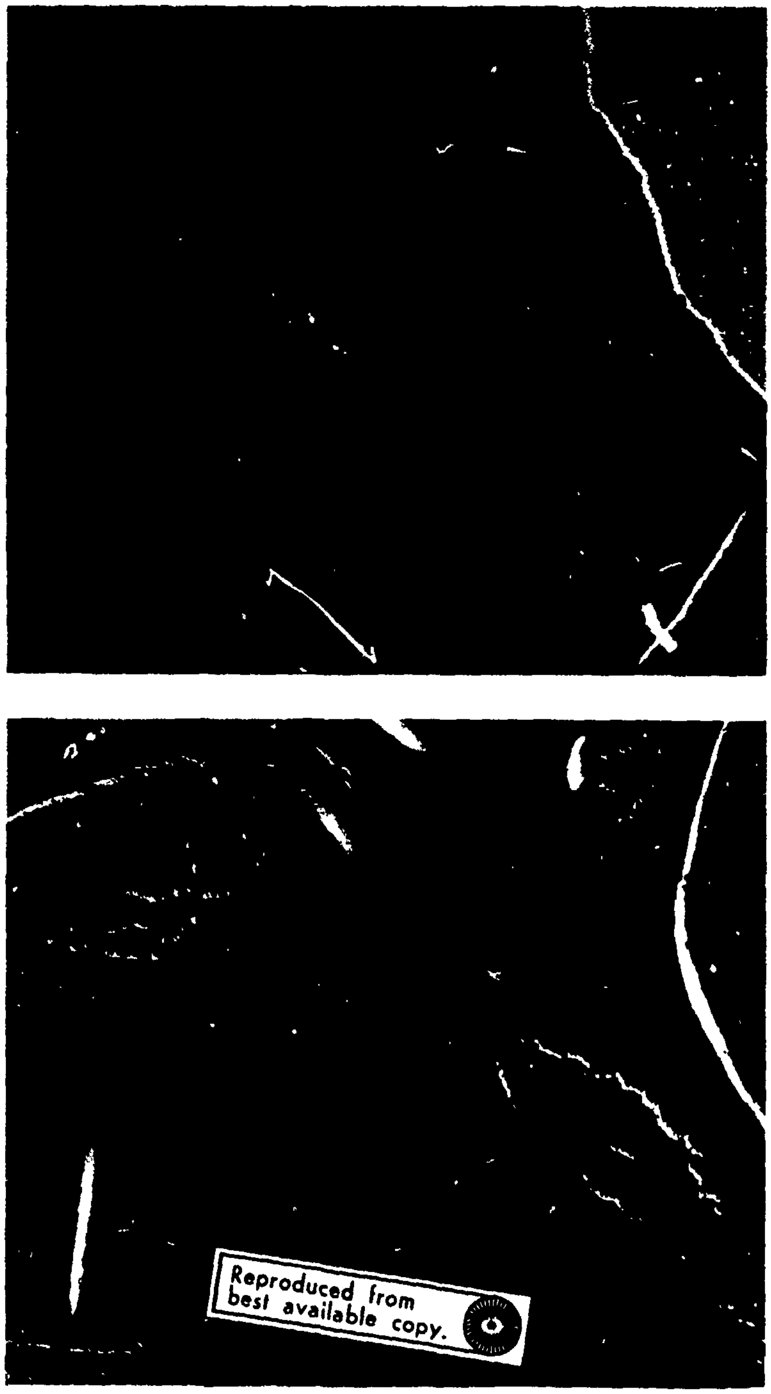

Figure 1.--Tracheid walls in transverse section, (a) latewood and (b) earlywood, showing compound middle lamella (CML), S_1, S_2, and S_3 layers of secondary wall, and helical thickening (HT).

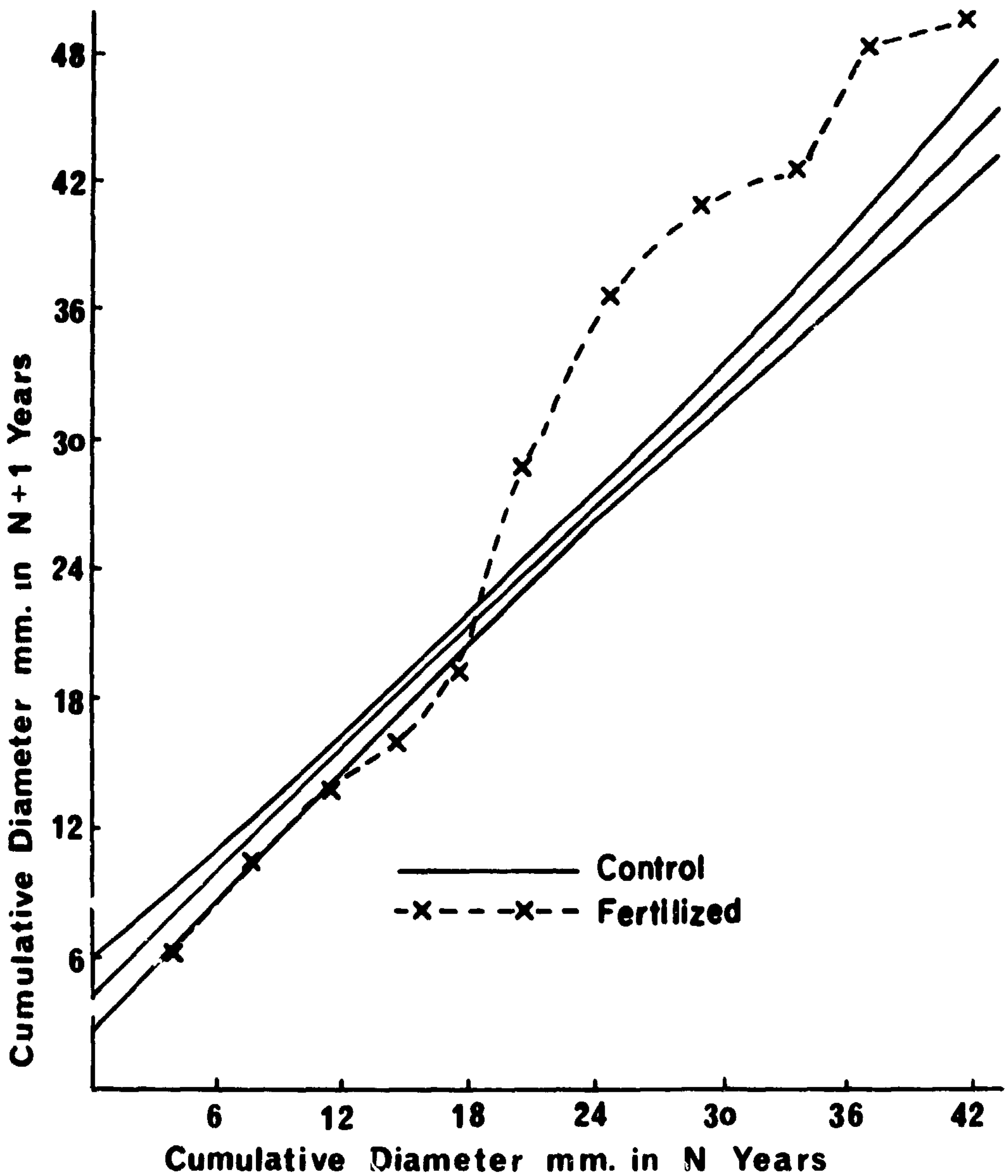

Figure 2.--Finite difference curve illustrating the mean response in diameter growth of the sample trees to fertilization. Rejection limits at the 0.05 probability level, calculated from cumulative diameter growth data of untreated trees, define the statistical limits for the determination of significant responses of fertilized trees in any year. The cumulative diameter growth of the outer 12 annual rings only is considered.

Physical Characteristics of the Wood

The mean specific gravity of the outer 7-year increment of wood from fertilized trees (0.424) was approximately 10% lower than that of the control trees (0.466). Using these specific gravity values, the stated plot volume increase of 74% is diminished to 67% when productivity is calculated on a weight basis. This is still an impressive result.

$$74\% \text{ volume increase} \times \frac{0.424}{0.466} = 67\% \text{ weight increase}$$

Comparisons of the number of cells in radial file within the earlywood and latewood of the fourth ring from the cambium are listed in table 2. In this particular ring, at the midpoint of the 7-year treatment, a substantial increase in the number of earlywood cells as a result of fertilization is indicated, while a corresponding increase in the number of latewood cells is slight. While these values are quite consistent with the observed decrease in specific gravity, the percentage of latewood determined by radial linear measurement across all seven annual rings dropped only slightly from a mean of 33% in the controls to a mean of 31.5% in "fertilized" wood. The observed decreases in specific gravity and percent latewood are consistent with the findings of other investigations (Williams and Hamilton, 1961; Zobel et al., 1961; Posey, 1964).

Pulp Yield and Pulp Quality

Yield data from table 3 demonstrate that the wood produced by the fertilized trees consistently yielded more pulp than wood from control trees, the mean yield difference being 2.3% on an ovendry, unextracted basis. A simple "t" test confirmed that the fertilized and control yield populations are significantly different at the 5% probability level. Calculated on a pulp basis, this mean yield difference is approximately 4.5%. Admittedly, the kappa numbers of the "fertilized" pulps are slightly higher than those of the "unfertilized" pulps, consequently a slightly lower mean difference is probably more realistic.

The weight productivity figure calculated in the previous section can now be adjusted as follows:

$$67\% \text{ weight increase} \times \frac{48.2}{45.9} = 70\% \text{ weight increase}$$

Thus half of the loss in productivity which might be attributed to the lower specific gravity of fertilized wood has been recovered by properly accounting for a substantial gain in pulp yield per unit weight of wood. Further substantiation of this yield difference was obtained by pulping chips prepared from entire cross sections of the sample trees, each section including 31 annual rings. Even with the diluting effect of 24 untreated increments, the pulp yield from fertilized wood averaged 47.1% or 1.2% higher than the yield from control wood.

Table 2.--Physical characteristics of the wood subjected to pulping

Tree	Wood specific gravity	Latewood percent	Number of cells in radial file[1]	
			Earlywood	Latewood
Control 1	0.510	38	10	16
Control 2	.456	26	25	30
Control 3	.382	24	16	16
Control 4	.515	44	42	58
Mean.......	.466	33	23	30
Fertilized 1	0.452	33	28	33
Fertilized 2	.452	34	44	41
Fertilized 3	.370	35	25	23
Fertilized 4	.421	24	47	33
Mean.......	.424	32	36	33

[1]Measured only on the fourth annual ring from the cambium.

Table 3.--Pulp yield data

Tree pair[1]	Pulp yield (Pct. O.D. unextracted wood basis)			Pulp kappa number (100 ml. kappa)		
	Fertilized	Unfertilized	F minus U	F minus U	Fertilized	Unfertilized
1	51.1	47.3	3.8	0.2	25.6	25.4
2	47.8	45.5	2.3	1.1	25.3	24.2
3	46.8	44.6	2.2	1.9	31.3	29.4
4	47.2	46.1	1.1	3.1	32.2	29.1
Mean.....	48.2	45.9	2.35	1.6	28.6	27.0

[1]Each pair of cooks, as tabulated, was digested simultaneously in a single microdigester.

Part of the yield difference can be attributed to a lower alcohol-benzene extractive content in the fertilized wood. Average values for this property listed in table 4 show this trend which is similar to a negative correlation between extractive content and extremely accelerated growth rate found by Klem (1968). Growth increases of approximately 50%, however, have been reported by the same author to have little effect on extractive content in spruce and pine while Erickson and Lambert (1958) recorded increases in extractives with moderate growth increases in Douglas-fir.

Since latewood comprises approximately 33% of the wood by volume in this study, its proportion by weight must exceed 50%. The differences in extractives, then, between fertilized and control wood, probably do not account for more than 0.8% of the observed pulp yield difference, leaving about 1.5% to be identified.

In comparing the strength properties of pulps from the two wood types (table 5), it is apparent that the considerable change in specific gravity brought about by fertilization did not adversely affect pulp quality. Mean values of sheet density, burst factor, and tear factor for the fertilized and control pulps are nearly identical. Breaking length is slightly higher in the fertilized pulps.

In assessing the collective pulp yield and quality data, two factors which seemed to conflict were:

(a) With coniferous pulps, one generally expects an increase in sheet density, burst factor, and breaking length and a decrease in tear factor to accompany a decrease in wood specific gravity, at least if an increase in the proportion of earlywood is responsible for that decrease in specific gravity.

(b) Data are accumulating which indicate that in certain pine species, a within-tree increase in the proportion of earlywood will result in a loss of pulp yield, even when calculated on an ovendry, wood weight basis (Gladstone et al., 1970).

In general, the results of this study fit the conditions of (a) with allowance for the relatively small decrease in earlywood percentage which was observed and, perhaps, for the stability of the tear factor. A substantial increase in pulp yield coincident with a decrease in specific gravity and an increase in the proportion of earlywood, however, does not meet the conditions of (b). Both circumstances suggested that an increase in the proportion of the S_2 wall layer in earlywood cells which were found under the fertilizer regime may have contributed to this anomaly.

Measurements of wall component thicknesses and estimates of the relative proportions of important wall layers tend to support this resolution of the problem. The values in table 6 represent four-tree means for each property, the wood sample within each tree being restricted to the fourth ring from the cambium. It is significant that the compound middle lamella thickness of both earlywood and latewood and the secondary wall thickness of latewood all apparently decreased upon fertilization while the secondary wall thickness of earlywood alone increased. As a result, the proportion of secondary wall area relative to total cross section reflects a substantial increase in the earlywood control-to-fertilized comparison

Table 4.--Alcohol-benzene extractives content of the wood subjected to pulping

Treatment	Extractive content[1]	
	Earlywood	Latewood
	Pct.	Pct.
Fertilized	3.14	2.78
Control	4.13	3.28

[1] Each entry represents the mean alcohol-benzene extraction content of wood components from 4 trees.

Table 5.--Properties of pulp prepared from fertilized and control wood

	Fertilized					Control				
	Tree No.				Mean	Tree No.				Mean
	1	2	3	4		1	2	3	4	
C.S.F.............ml.	356	354	352	357	355	350	367	350	355	356
Beating time......min.	5.25	5.00	4.50	4.75	4.87	4.50	4.50	4.00	5.25	4.57
Density........g./cm.^{3}	0.714	0.658	0.680	0.719	0.693	0.680	0.649	0.741	0.680	0.688
Burst factor..........	76.6	71.9	74.6	77.1	75.1	70.5	71.5	81.9	73.8	74.5
Breaking length.....m.	10,590	9,460	10,540	11,130	10,430	10,070	9,840	10,960	9,550	10,105
Tear factor..........	102	135	112	95	111	115	127	91	98	108

Table 6.--Tracheid and tracheid wall characteristics as measured within the fourth ring from the cambium[1]

	Fertilized		Control	
	Earlywood	Latewood	Earlywood	Latewood
Fiber length..............mm.	3.8	4.0	3.5	4.0
Fiber width.................μ	53	29	55	31
CML[2] thickness..............μ	0.40	0.73	0.62	0.87
Secondary wall thickness.....μ	2.95	8.80	2.50	9.44
"Total" wall thickness.......μ	3.35	9.53	3.12	10.31
Secondary wall area.......pct.	94	96	89	94
S_2 layer area............pct.	79	89	70	88

[1]Each entry represents a 4-tree mean value.

[2]Compound middle lamella.

while the same comparison in latewood shows a much smaller difference. The contrast between these same comparisons when the proportion of S_2 wall area relative to total cross section is considered is even more evident. The proportion of S_2 is nearly constant in latewood, but in earlywood it has increased some 13%.

The high-cellulose content of the S_2 layer in coniferous tracheids is well documented, hence an increase in the proportion of this component should result in increased pulp yield. Though the mean secondary wall thickness of latewood decreased under fertilization, the associated compound middle lamella did likewise, resulting in a thinner "total wall" but also in a wall with nearly the same proportion of the all important S_2 layer. The relative constancy of gross fiber width and length suggests that the fertilization-induced decrease in the "total wall" thickness of latewood could be responsible for the general decrease in wood specific gravity attributable to fertilization. Thus one can start to feel more comfortable about the concurrence of:

(a) A decrease in specific gravity, control to fertilization.

(b) A relatively small decrease in percent latewood, control to fertilization.

(c) A substantial increase in pulp yield, control to fertilization.

The detailed examination of the fourth ring from the cambium in each tree supports the hypothesis that much of the observed increase in pulp yield is a result of an increase in the proportion of S_2 layer in earlywood tracheids. Furthermore, fertilization tended to make earlywood and latewood more alike, thinning the walls of latewood tracheids and thickening those of earlywood tracheids. Increasing the uniformity of fiber furnish in such a fashion is desirable for most papermaking applications.

Summary

The apparent, major effects of fertilization on the Douglas-fir trees and wood examined can be summarized as follows:

(a) An increase in wood volume productivity, a favorable circumstance.

(b) A decrease in wood specific gravity, usually favorable with respect to most pulp strength properties, but detrimental to pulp yield per unit volume of wood.

(c) An increase in pulp yield per unit weight of wood, a favorable circumstance.

The last effect, yield per unit weight of wood, merits special consideration. Wangaard (1958) cites evidence which indicates that, for a chemical process well adapted to the pulping of a particular species, the variation in yield per unit weight of wood which is attributable to the chemical composition of that wood is

slight and seldom exceeds 3%. It should be pointed out, however, that many conventional pulping processes produce about 50 pounds of pulp for every 100 pounds of dry wood introduced. An increase of 3% in pulp yield per unit weight of wood (calculated on a wood basis) is thus equivalent to a 6% increase in pulp yield calculated on a pulp basis.

An example of kraft pulpmill costs which would be directly affected by changes in pulp yield per unit weight of wood at constant specific gravity is presented in table 7. These figures represent reasonable estimates of operating costs only and are appropriate for a bleachable grade of screened kraft pulp (pine) in slush form. Whether considered as extra pulp produced at no cost or as a reduction in cost per ton applicable to the entire mill output, a 1% increase in yield per unit weight of wood can justify considerable effort to realize it. It is becoming apparent that significant amounts of genetic and environmental variability in weight-based pulp yield do exist and activities by which this property can be controlled should be developed.

Table 7.--An example of kraft pulpmill costs which would be directly affected by changes in pulp yield per unit weight of wood[1]

	Approximate Cost per Pulp Ton	
A. Stock Cost		
1.6 cords per ton at $19 per delivered cord	$30.00	
Wood handling	2.50	
Pulping chemicals	3.00	
Total stock cost		$35.50
B. Conversion Costs		
Labor	2.50	
Maintenance and supplies	4.00	
Power, steam, water	3.00	
Total conversion cost		9.50
C. Total Pulpmill Operating Cost		$45.00

At 500 tons per day, total pulpmill operating cost = $22,500.
Each 1% increase in yield, pulp basis - $225 per day.
Each 1% increase yield per unit weight of wood = $450 per day.

[1]These figures represent operating costs only and are appropriate for a bleachable grade of screened kraft pulp in slush form.

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Tarkow, FPL--What about the permanence of the urea treatment over a 7-year period?

Siddiqui--We don't have any information about whether the nutrient status of urea has changed over the years. We suspect that the response indicates that the nutrients are available to the trees even after 7 years.

Strand, Crown Zellerbach--In general, the response peaked in 2 years and then trailed off. We're pretty certain that we got most of our effect by uptake in the crown and redistribution in the crown after the initial application. Four hundred pounds isn't obviously our standard rate, but the people at Syracuse wanted some of our best samples, so we went there for them.

Gordon--On the variation in lignin content that was shown in the slides, were the measurements made after extraction?

Siddiqui--Yes, we extracted the wood and these measurements are based on extractive-free ovendry wood weight.

Gordon--Was percent summerwood about the same for both?

Siddiqui--Yes, it is a difference of about 2%, I think. There is a slight reduction in tracheid diameter, too, a micron or two. Another thing to remember here is that he way summerwood is measured is not actually indicative. One can put an arbitrary boundary between the two. The number of cells, I think, is a better indication of the distribution of the cells within the growth ring.

Gordon--Under the same cooking conditions, did the charges always arrive at the same kappa numbers?

Siddiqui--We took a pair of chip charges, each 50 grams; one was from fertilized trees and the other was from control. We cooked these two charges together, of course in a separate mesh, in a single microdigester under the same conditions. So we had four pairs of pulp, one from fertilized and another from control, and both pairs were pulped under the same conditions. Yield differences are consistent. We

didn't have enough wood to cook the wood for constant kappa number. The kappa number in the case of fertilized trees was slightly higher, 28.6 compared to 27 for the control. And we think that this slight difference in kappa number doesn't have much effect on pulp yield differences from what we observed.

Gordon--What about speculating on the differences of yield, in view of what was shown relative to the lignin contents and the holocellulose?

Siddiqui--We think the increased yield in case of fertilized trees is due to a higher content of secondary walls in the earlywood. As I showed, the increase in the relative area of secondary wall in case of fertilized trees is 13% more than controlled trees. That is quite a high increase.

Gordon--Are there statistical differences in the results obtained?

Siddiqui--The differences between controlled and fertilized trees were significant at the 5% level.

Bengtson, TVA--I think it is generally recognized that the response to nitrogen fertilization in conifers generally is bell shaped in regard to time. Were individual rings analyzed to actually show whether or not such wood exists or did exist in this study?

Siddiqui--For this fiber wall characteristic we didn't examine all the increments, only one increment in each tree--the fourth year from the date of fertilization.

Gordon [summarizing]--There remains the question as to the advisability, if I may put it that way, of using the extractive-free wood density for this type of correlation.

Siddiqui--The wood specific gravity data which I presented here is not based on extractive-free wood. That is unextracted wood. The figures I gave for extractive content attempt to show that some yield differences would be due to more extractive content in fertilized trees.

Question--How did you separate secondary wall pulp from any other wall pulp?

Siddiqui--In Douglas-fir, the S_3 layer is quite obviously due to presence of thickening, especially in the earlywood. There was quite a good bonding between S_1 and S_2 especially. Because the fiber stem grew here at that layer also, I could distinguish between the S_1 and S_2 on the one hand and S_3 and S_2 on the other hand.

?????--You're just referring to the S_2 relative to S_3 and S_1?

Siddiqui--Yes.

Gordon--Between the trees that had been fertilized and those that hadn't, did you notice any difference in that shearing between that fiber wall?

Siddiqui--No, and it appeared the same in both.

Gordon--What about additional information relative to the soil conditions that existed, was this area especially nitrogen deficient? What were the conditions?

Siddiqui--A paper coming later on will explain more about the soil conditions. We have limited information about the area we got wood samples from, so I can't say much about the soil conditions.

Gladstone, Syracuse--It is an area where we have a very fine nitrogen response in general. I don't think you'd characterize it as a very poor site or an unusual area.

Gordon--We have a question about selection of the fourth ring since that it has been pointed out that the key growth was within the second year.

Siddiqui--For one thing it was in the center of that particular growth period we were looking into and growth tends toward maximum at that portion in the case of fertilized trees.

Wellwood, University of British Columbia--Were the fertilized trees selected because they showed a decrease in specific gravity? We have found Douglas-fir with increased specific gravity with fertilization, with 200 pounds of nitrogen.

Siddiqui--We got wood samples from eight trees, four fertilized and four control, and we didn't make any selection among them. We made up the wood specific gravity on all eight of them and compared the wood specific gravity of fertilized with control.

Strand, Crown Zellerbach--The request was for the best we could find in terms of growth rate. We made no selection based on specific gravity.

EFFECT OF IRRIGATION AND FERTILIZATION

ON WOOD QUALITY OF YOUNG SLASH PINE

by

DIANA SMITH[1]

HAROLD WAHLGREN[1]

GEORGE W. BENGTSON[2]

Because of an anticipated shortage of timber and wood fiber, there is a growing interest in accelerating wood production through the use of intensive cultural practices such as irrigation and fertilization. While some information concerning the effects of such cultural practices on wood structure has been available in this country (Mitchell, 1939; Paul and Marts, 1931; Posey, 1964; Foulger and Hacskaylo, 1968; and Howe, 1968), there has been little opportunity to evaluate a fully replicated field experiment involving both irrigation and fertilization on a major commercial species.

In 1970 the Tennessee Valley Authority (TVA) was conducting a first thinning in a 6-year-old slash pine (*Pinus elliottii* Engelm.) plantation that had been irrigated and fertilized at prescribed levels since its inception. At TVA's request, the U.S. Forest Products Laboratory evaluated the wood quality characteristics of a limited number of these trees.

The purpose of this study was to determine the effect of prescribed levels of irrigation and fertilization on the wood quality characteristics of young slash pine. The primary quality characteristic evaluated was the specific gravity of the clear wood between branch whorls in the natural and extractive-free condition. Secondary characteristics included grain orientation, the clear length between branch whorls, number and diameter of branches per whorl, and the percentage of latewood in the annual rings.

Description of Experimental Area

The plantation was established using 1-0 seedling stock in January 1964 within TVA's Forest Fertilization Area in west-central (Citrus County) Florida. The soil is an infertile, excessively drained sand (Astatula fine sand) having typical properties for the type with the exception of being unusually high in total and

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available phosphate. Rainfall is abundant in the area, averaging nearly 60 inches annually, but its distribution is decidedly seasonal, with droughty spring weather and rainy summers the rule.

The experiment was laid out according to a split plot design. Four levels of irrigation comprised the main treatments and two levels of fertilization the subtreatments. These treatments were replicated in four randomized blocks. Each main plot measured 120 by 220 feet (0.6 acre) and each subplot 120 by 110 feet (0.3 acre). Within each subplot, trees were planted in 11 rows with 10-foot spacing between rows and 6-foot spacing between trees within a row. To avoid possible border effects in trees growing close to plot boundaries, a root pruner was used several times each year to sever lateral roots growing outward from each plot. There were originally 200 trees per 0.3-acre subplot, of which approximately 175 have survived.

The empirically derived irrigation regimes were as follows: (1) Control (no irrigation); (2) low level--irrigate when soil moisture deficit (D) reached 25% of maximum potential available water (A) in surface 6 feet of soil; (3) medium level--irrigate when D reached 50% of A; and (4) high level--irrigate when D reached 100% of A. The maximum potential available soil water (A) of Lakeland fine sand is 0.80 to 0.98 inch of water per 3-foot soil profile (according to ARS-USDA data) and in this experiment the figure for A (6-ft. profile) was set at 2.00 inches. The system of irrigation, consisting of an 8-inch well, turbine pump, and aluminum mains and perforated pipes, was installed in August 1964, and irrigation has been applied, when needed, continuously since that date.

Fertilizer was applied in January 1964 to plots selected for fertilization with additional applications at 2-year intervals according to the schedule shown in table 1. The paired subplots received no fertilizer.

Procedures

Field Sampling and Collection

To minimize border effects, sampling on each 0.3-acre subplot was confined to the center five rows and excluded the three trees closest to the end of each row. From each of these rows, one tree was selected at random to provide five trees from each of 32 subplots. From these five trees, cross sections measuring 5 inches along the grain were taken from the middle of the 1965 and 1967 annual height increments for specific gravity determinations. In addition, one of the five trees from each subplot was selected at random for more intensive investigation and the entire stem was taken to the Forest Products Laboratory for measurement. Thus a total of 320 cross sections (8 treatments x 4 replications x 5 trees x 2 heights) and 32 intact stems (8 treatments x 4 replications) were removed from the field.

Table 1.--Schedule of the amount, type, and time of fertilizer application

Year*	Materials applied in pounds per acre	Nutrient application, pounds per acre of N, P, K, Mg, S
1964	600 lb. rock phosphate	83 lb. P
	400 lb. TVA leached-zone fertilizer (20-20-0)	80 lb. N, 35 lb. P
1966	300 lb. ammonium nitrate	100 lb. N
	200 lb. potassium magnesium sulfate	36 lb. K, 22 lb. Mg, 44 lb. S
1968	476 lb. TVA diammonium phosphate (21-53-0)	100 lb. N, 111 lb. P
	100 lb. potassium chloride	50 lb. K
Total application		280 lb. N; 228 lb. P; 86 lb. K; 22 lb. Mg; 44 lb. S

*Early spring application.

Laboratory Procedures

From each of 320 cross sections, representing the 1965 and 1967 annual height increments, a thin cross-sectional wafer measuring 1/8 inch along the grain was cut for determination of extractive content. The wafers were ovendried, weighed, and then extracted for 5 days in a 2:1 (by volume) mixture of alcohol and benzene in a Lloyd extractor. After extraction, the wafers were ovendried and reweighed. Extractive content was calculated from the difference between ovendry weights expressed as a percentage of the unextracted dry weight.

Immediately adjacent to the thin wafers, a cross section measuring 1 inch along the grain was cut and jointed for measurements of annual ring width, the widths of the earlywood and latewood zones within the annual rings, and specific gravity. Measurements were made along two diameters at approximately 90° to each other with a dual-linear micrometer. The percentage of latewood within the annual rings was calculated on a cross-sectional area basis.

Specific gravity was determined for the 1-inch cross sections by the water displacement method (dry weight and water-swollen volume basis) in the unextracted condition. Extractive content, determined on the wafers, was used to adjust the corresponding specific gravity values to an extractive-free basis.

On each of the 32 intact stems (that is, prior to removal of the 5-in. along the grain cross sections from the middle of the 1965 and 1967 height increments) the length between height increments was measured and the average diameter outside bark determined from measurements of two diameters at the midpoint of each height increment. The stems were steamed in an autoclave and then debarked with the branch stubs trimmed parallel to the surface of the stem.

For estimates of knot diameter on the 32 tree stems, the number of knots was counted and surface diameter of each knot was measured and recorded.

Estimates of the wood grain orientation were made along the length of the entire 1969 growth increment. A vertical axis was established and marked on the stem and then a scribe used to mark the grain orientation. A transparent protractor was then used to read the deflected angle. This procedure was repeated at four points along the circumference of the stem.

Analyses

Data collected from the 1965 and 1967 annual height increments was averaged for the five trees from each subplot to provide a subplot mean for the observed characteristics. Treatment effects were evaluated separately for each of the two height increments according to the following analysis of variance:

Source of variation	Degrees of freedom
Blocks	3
Irrigation (I)	3
Error 1	9
Fertilizer (F)	1
FxI	3
Error 2	12
Total	31

Results and Discussion

While cross-sectional area growth increased significantly in response to both irrigation and fertilization, the specific gravity of the wood was relatively unaffected by treatment (fig. 1). That is, irrigation had no significant effect at either sampling height and fertilization reduced specific gravity only slightly (approximately 0.008) and only in the 1967 height increment. Analysis further showed that latewood percentage on an area basis followed the same trend as specific gravity as it too was significantly affected (5% level) only by fertilization and only in the 1967 height increment (fig. 2). Fertilization also increased the amount of alcohol-benzene extractives at the lower position (1965 height increment). The increase was significant at the 1 percent level (fig. 2).

Plotting of the latewood percentage curves based on individual annual rings shows the paramount importance of rings from pith on position in the tree when the rings were laid down (figs. 3 and 4). It also shows that without irrigation, fertilization lowered the amount of latewood formed within the annual ring and likewise lowered the cross-sectional area growth. When supplemental moisture was made available (irrigation), fertilization did not appear to affect the latewood percentage but significantly increased the cross-sectional area growth.

Another rather interesting observation was spiral grain angle. On the basis of 32 trees (1 per subplot), irrigation consistently reduced the angle of spirality (measured under the bark along the length of the 1969 growth increment). Fertilization, on the other hand, had no consistent effect on spiral grain angle.

Although the average number of branch whorls, branches per whorl, and branch diameter did not appear to be affected by treatments, the average clear length of stem between branch whorls increased in proportion to the amount of irrigation from 23 to 30 centimeters. Fertilization, however, showed no consistent effect on these parameters.

In summary, the most significant findings are:

(1) Irrigation and irrigation plus fertilization greatly increased stem cross-sectional area growth.

(2) Irrigation reduced the spiral grain angle along the length of the stem and increased the clear length between branch whorls, but did not affect the specific gravity of the wood.

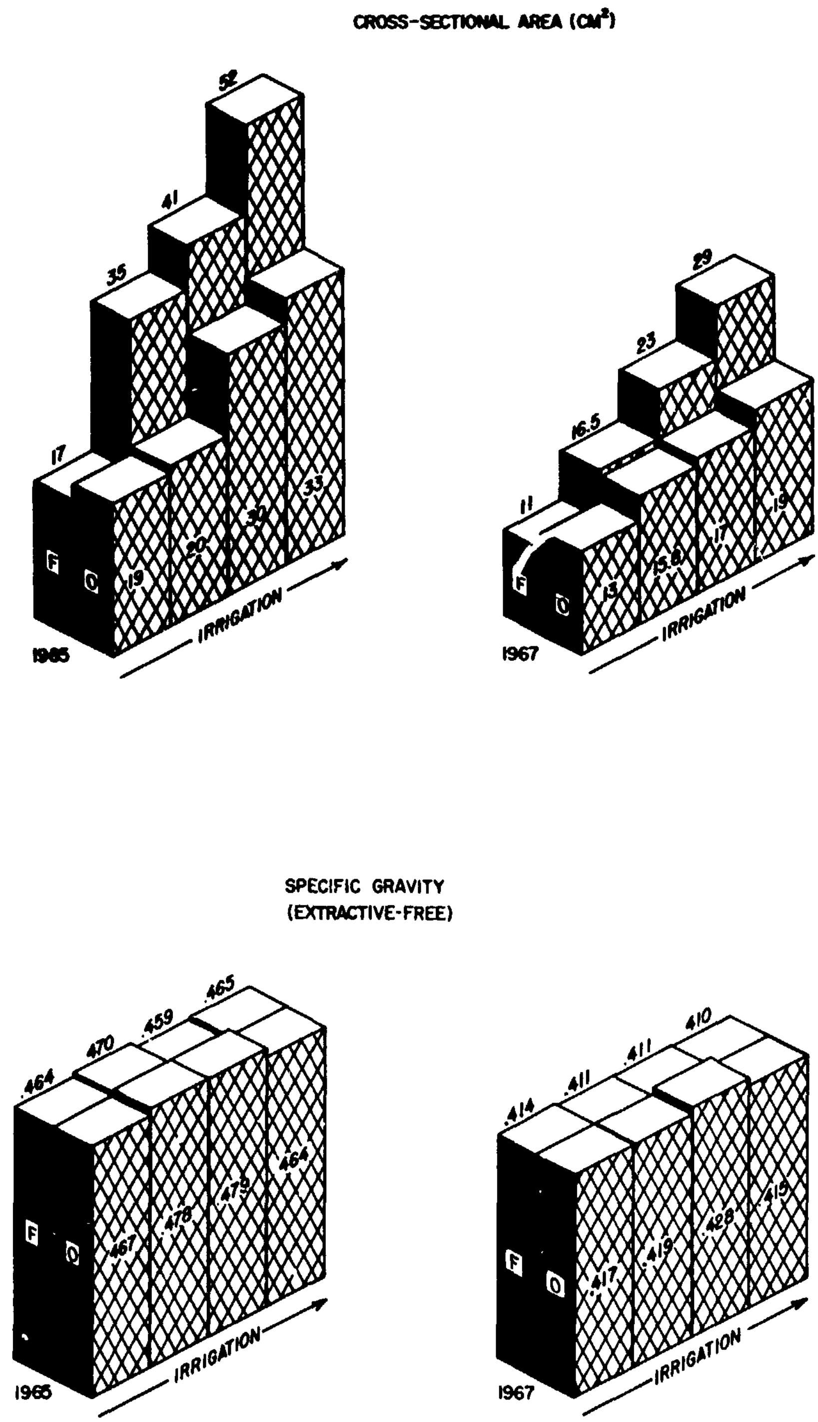

Figure 1.--Effects of fertilization and irrigation on the cross-sectional area growth and extractive-free specific gravity of 6-year-old slash pine samples taken from the 1965 and 1967 height increments. Values are averages of 20 trees per treatment.

F = Fertilizer
O = No fertilizer

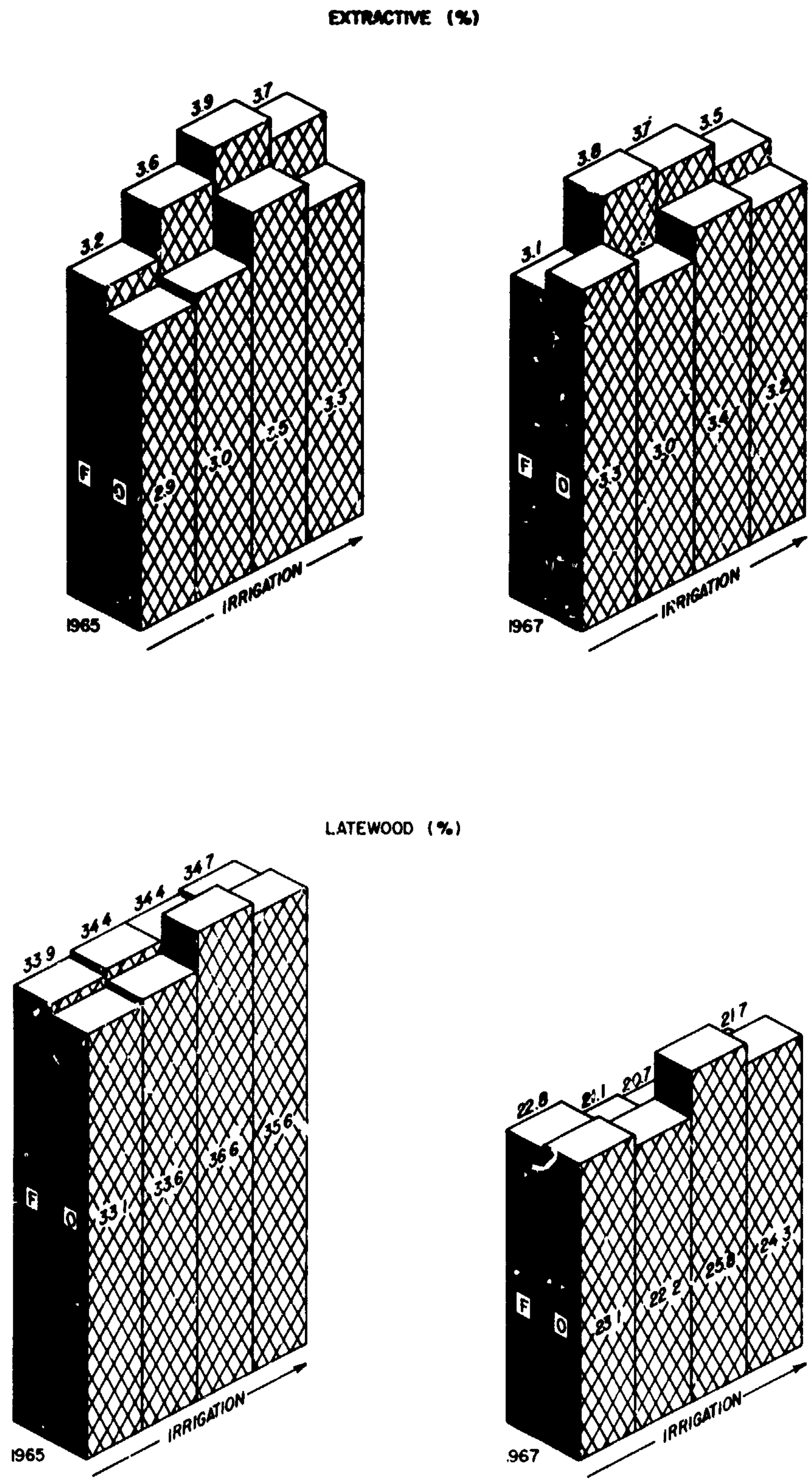

Figure 2.--Effects of fertilization and irrigation on the percentage extractives and percentage latewood of 6-year-old slash pine cross sections from the 1965 and 1967 height increments. Values are averages of 20 trees per treatment.

(M 139 657)

F = Fertilizer
O = No fertilizer

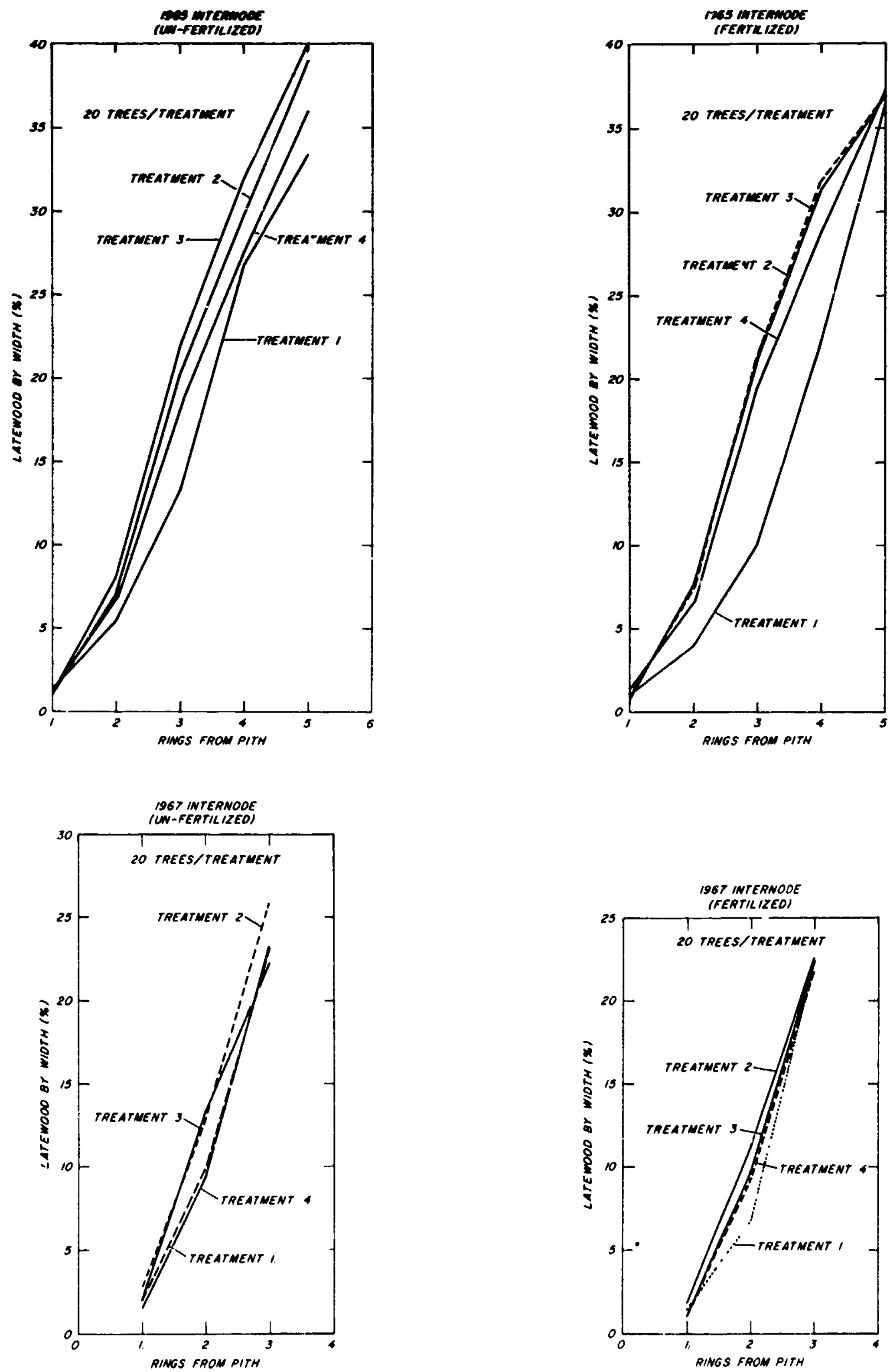

Figure 3.--Effects of irrigation and fertilization treatments on the relationship between percentage of latewood and rings from pith for two heights in 6-year-old slash pine trees. Irrigation treatment codes are 1, control, no irrigation; 4, low level irrigation; 3, medium level of irrigation; and 2, high level of irrigation.

(M 139 672)

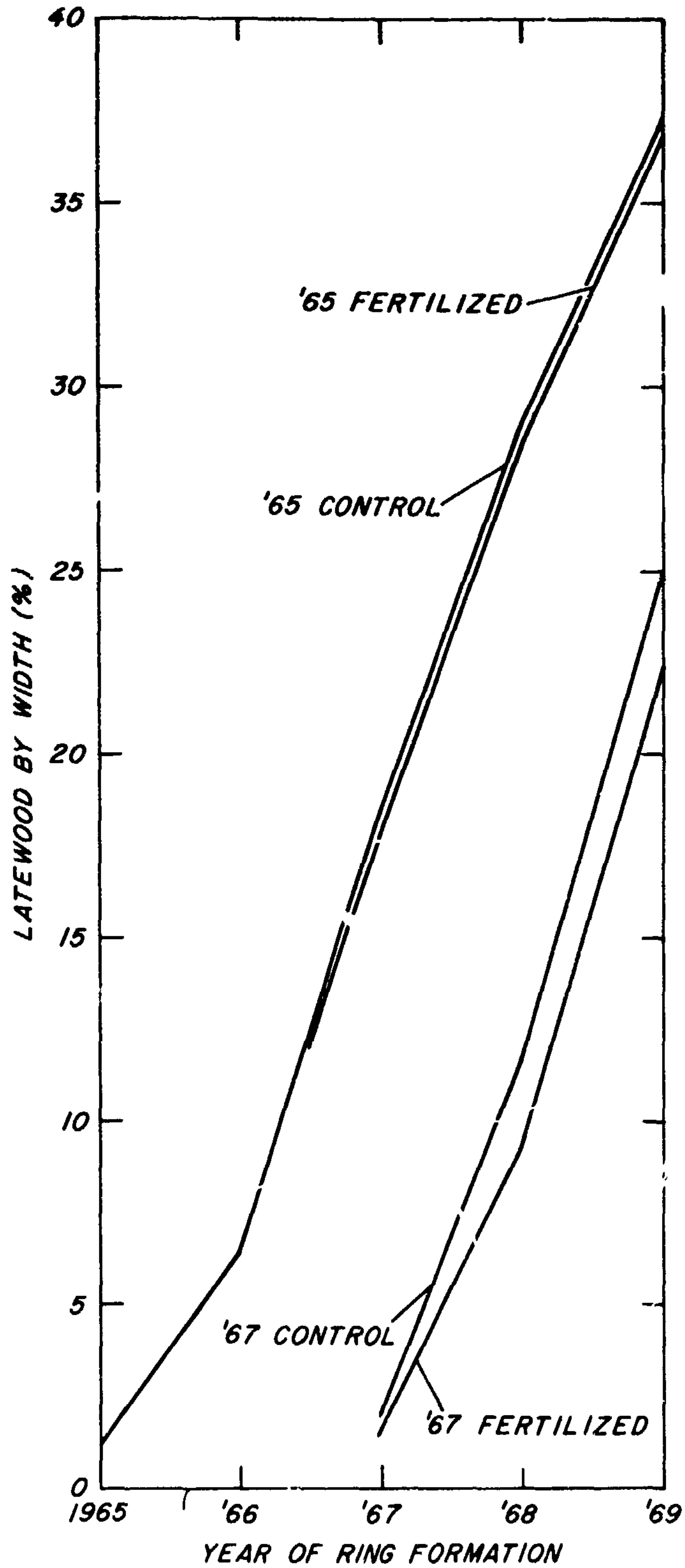

Figure 4.--Effect of fertilization treatment on the relationship between percentage latewood and year of ring formation for the 1965 and 1967 height increments in 6-year-old slash pine trees. Plottings reflect averages from 80 trees. (M 139 671)

(3) Fertilization reduced the specific gravity of the wood and latewood percentage at the upper position in the stem (1967) and increased the amount of alcohol-benzene extractives at the lower position (1965).

(4) Neither irrigation nor fertilization affected the average number of terminal growth flushes, the average number of branches per whorl, nor the average branch diameter.

These stem cross-section data and results with other growth parameters soon to be published elsewhere confirm the general hypothesis that response to fertilizers by forest trees may be limited, indeed precluded, on certain sites where soil moisture is deficient, even as in this case where the deficiencies occur during only a part of the growing season. The absence of any effect of irrigation on wood specific gravity has considerable biological and practical significance. But it should be recognized that irrigation was administered on a 12-month basis which probably increased the amount of earlywood produced during a normally droughty spring and also prolonged the period of latewood growth. The results might have been quite different had irrigation been confined to either spring, or summer and fall, or if the experiment had been conducted on a similar soil in a climatic zone characterized by a different rainfall distribution pattern, e.g., with moist springs and dry summers as in the West Gulf region.

The very small negative effect of fertilizer without irrigation on tree growth observed here was not significant but would not be entirely unexpected. All the young trees were growing in competition with a vigorous understory which was stimulated by fertilization and irrigation. In the absence of irrigation the increased competition for available soil moisture could be critical. Also, under drought conditions, the addition of fertilizer may increase the osmotic pressure of available soil moisture and impose an even greater moisture stress on tree growth. Such a negative effect of fertilization was observed by Dickson for black walnut seedlings grown in sandy soil under drought conditions (1971). On similar sites older pine stands with closed canopies and no understory might well respond to the fertilizer treatments imposed here, even without irrigation. Certainly fertilizer responses on the poorly drained P-responsive soils of the Lower Coastal Plain would be different (Pritchett and Smith, 1970).

The finding that neither fertilization nor fertilization plus irrigation had any pronounced effect upon specific gravity of the wood is in contrast to Posey's (1964) findings with loblolly pine. It should be noted, however, that Posey's trees, 12 and 16 years old at fertilization, were past the age when "juvenile" wood is typically laid down, whereas all the wood produced in our trees would be regarded as juvenile. Apparently in Posey's trees, nitrogen fertilization caused a temporary reversion toward wood of lower specific gravity.

The results reported here are but a first step toward characterization of irrigation and fertilization effects on the tree components of this particular ecosystem. Detailed results on growth, biomass, and nutrient content of these same trees are soon to be published. We intend to make repeated thinnings at intervals of 4 to 5 years in this plantation, with further wood analyses aimed particularly at the effects of the cultural factors on the onset of the transition from "juvenile wood" to "mature wood."

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* * *

Question--To what do you attribute the retarding effect of the application of fertilizer to the low irrigation level?

Wahlgren--That one of course was no irrigation at all. I think moisture was just becoming a limiting factor at that stage of the game. You've reduced the percent of latewood and therefore you're going to reduce the specific gravity.

Shoulders, Forest Service--George, you have good growth measurements on these plots. Does this negative response to fertilizer without irrigation show up on your height and diameter growths?

Bengston--Yes, it does. It shows up in both height and diameter; any parameter of growth, it's there. In some cases it is marginally significant, but it is a real difference and I think it related to this competition problem.

Franklin, Forest Service--Do you have any comments or explanations for the increase in extractives with the treatment?

Wahlgren--No, I really do not.

Franklin--An increase in latewood could contribute. Generally you may find higher levels in latewood, and I think it may be more site-related in this case than anything else, since you are really talking about slash pine on this site. Without treatment it's really off site. It is at a low vigor level in general compared to what slash pine should do. And at lower vigor levels, particularly with moisture stress, we will get less extractive production than we might on a normal slash pine site. As soon as you ameliorate the site to improve it in terms of growth, you bring it up to what might be normally expected in terms extractive production.

Wahlgren--This is why the last statement I made was to emphasize that this applied only to that particular site.

Zahner, University of Michigan--The volume growth is related to both cross-sectional area and the height. Could you indicate as to the maximum difference between the poorest growth and the best growth, and the poorest treatment and the best treatment, in terms of percent increase in total volume?

Wahlgren--No, I couldn't without extracting some more of the information. The only thing we had to go on were those 32 intact trees where we had complete diameter measurements and so on. George has the height and diameter data; have you put that together yet?

Bengtson--This is not published yet, but we have done also biomass studies on this stand. At the same time Gus took some of the trees for analysis, we chopped some of them up and made a very detailed biomass measurement. As I recall, there was about a three-fold increase in biomass between the control, and the fertilized irrigated treatment.

?????--Per acre?

Wahlgren--Per acre. If you had just looked at our cross sectional areas there and averaged those out to see what the percent increase was, the maximum amount was about 110%.

Bromley, American Pulp Wood Association--An act of Congress this month has made this type of study especially interesting and significant. The Water Quality Act of 1971 is going to require that all water issued from manufacturing plants, I think by 1980, must be free of all pollutants. Now if the company finds it impossible or uneconomical to remove these pollutants, they might flood this water in irrigation through some of their plantations. Have you any comments as to the possibility of using the effluent from mills in studies in irrigations of this type?

Wahlgren--Yes, I think there is a distinct possibility. Now I'm going to open the door here again because some of the things weren't commented upon. George, why don't you tell them what happened to the pH on these soils with this irrigation to give you an idea of one of the problems.

Bengtson--This irrigation water that we are using in this area comes from Ocala limestone in Florida; it is a deep well. And this water is very high in calcium and magnesium carbonates. So we have a confounding effect in this equipment--wherever we applied irrigation water, we were also liming the soil. In the most intensively irrigated plot the pH has gone from 5.0 to 6.6 and 6.7. We were quite frightened when first we saw this trend; we were afraid we were going to get into iron-deficiency problems because a high pH condition with conifers means you can get lime-induced iron deficiency. However, it seemed to stabilize at this point and apparently the acid-producing litter is counteracting the liming effect of water. But this is one of the things you get into in this type of study. I think there are people in the audience who have had experience with pulpmill effluents added to forest soils. Maybe Gene Shoulders hasn't directly but some of his people at Alexandria have done this type of work. Gene, do you have anything to say about that?

Shoulders--Several years ago at Alexandria we did a series of pot studies. Really they were 55-gallon drums using a number of different strengths of effluents on a very poorly drained soil. These were undisturbed soil cores in the barrels using slash pine. On this particular soil the problems of being able to dispose of enough water to make it practical seemed to be insurmountable. But from what we learned of salting of the soil and other responses to pines, I think there is a possibility of disposing of these effluents on some of the coarser textured soils. I think there are problems here that go way beyond whether you're looking for growth responses or not; if you can keep a living p[illegible] out there to pull out the moisture that you're putting into the soil, the grow[illegible] responses that you may get may not be of any economic importance to you. Down [illegible] our country we figure, on fully stocked stands, you can pull some 8 inches of water. This is Bob Zahner's work and it's held up pretty well. We got about 8 inches of water out of the soil during the summer months.

Wahlgren--Initially we were surprised in what TVA was doing down there in Holder. When we got down there, it was just like taking a kid in a candy machine. George had so many experiments and maybe he can briefly mention a few points on using waste and sewage disposal plants?

Bengtson--The experiment Gus referred to is one where we're using composted municipal waste in a treatment to evaluate just how much of this compost we can apply to a forest situation without inducing untoward effects in the forest vegetation. In one of our experiments at Holder we have gone up to 40 tons per acre, dry basis, of composted municipal waste applied to a young slash pine plantation without any deleterious effects. In fact, there were some positive effects. So we may find that the forest is a good ecosystem for the disposal of noxious wastes.

Auchter, FPL--Forty tons per year?

Bengtson--No, this was a single application. Our data made on the soil during this 2-year period indicated that about 90% of the organic material which was applied originally had been oxidized, essentially during that 2-year period. So we speculate that one could probably apply as much as 40 tons per acre on, say a 3- or 4-year cycle.

Wahlgren--Particularly on that sandy soil down there.

Bengtson--Yes, in Florida.

EFFECTS OF FERTILIZATION ON STEM, WOOD PROPERTIES, AND PULPING CHARACTERISTICS OF SLASH PINE (PINUS ELLIOTTII VAR. ELLIOTTII ENGELM.)[1]

by

JAMES W. GOODING[2]

W. H. SMITH[3]

Abstract

Fifteen-year-old slash pine on a phosphorus (P) -deficient site produced nearly seven times more volume than unfertilized trees after receiving 115 pounds P per acre in a mixed fertilizer at planting. Sample trees were felled, precise measurements made, and samples taken at several bole positions to facilitate comparison of bark thickness, stem form, specific gravity, wood and paper quality between fertilized and unfertilized trees.

Bark thickness was decreased by treatment but only at stem positions between 8.0 feet and crown base. No difference in absolute form class occurred due to treatment. Wood specific gravity was not reduced by treatment but fertilization altered specific gravity trends in the stem. As a result, pounds of dry wood per cubic foot are slightly reduced, but this loss will be more than offset by large volume increases due to treatment. Kraft pulping and handsheet studies indicate no important differences in yield but some possibly beneficial changes in paper quality.

* * *

Fertilizer use in southeastern forestry increased over fivefold last year. Thus, it is important that stem and wood properties associated with increased growth rates from these materials be characterized. Several researchers (Williams and Hamilton, 1961; Pegg, 1966; and Broerman, 1970) have noted differences in wood specific gravity, stem form, and bark thickness primarily in response to nitrogen fertilizers. Research to date does not indicate that phosphorus affects specific gravity in young pine (Pritchett and Swinford, 1961; and Gentle, et al., 1968). The effects of phosphorus on other stem or wood properties are not known.

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Stem form and bark thickness can influence estimates of merchantable wood and also affect the quantities of waste generated in processing. Specific gravity is correlated with fiber yield and quality of the pulped products. Thus, a study was initiated to compare stem form, bark thickness, specific gravity, wood properties, and pulping characteristics of slash pine markedly stimulated by fertilizers with adjacent slash pine having much slower growth rates.

Materials and Methods

Slash pine was sampled from three areas, two of which were from a fertilization field test established in 1953 by personnel of the St. Joe Paper Company and the University of Florida. This 2-acre area was divided into four 0.5-acre blocks which were double-disked after application of 2 tons per acre "mill waste" liming material. Two blocks received 1 ton per acre of 2-12-12 commercial fertilizer surface broadcast (40, 115, and 150 lb. per acre, respectively, NPK).

Trees receiving fertilizer have maintained a rapid growth rate for 15 years. Site quality for these plots is 80 feet at 25 years (Barnes, 1955). Fertilized trees averaged 8.2 inches diameter at breast height (DBH) and 57 feet total height. The unfertilized area has a site quality of 50 feet. Trees in this area averaged 4.1 inches DBH and 30 feet total height. The element responsible for the increased tree growth could not be determined in this experiment because a mixed fertilizer was used. However, response is attributed primarily to the P component. Results of subsequent local experiments (Pritchett and Llewellyn, 1966) and soil and foliar nutrient analysis support this conclusion.

Certain parameters chosen for study are inherently dependent on tree size (e.g., bark thickness, see Miller, 1961). Comparisons yielding more meaningful information were thought to be gained by relating characteristics of fertilized trees with unfertilized trees of the same approximate size growing on a similar soil. Therefore, plots were established in a 17-year-old slash pine plantation adjacent to the 15-year-old fertilizer trial. Site quality for this area was 65 feet. Trees from this control area were grown at the same spacing, on the same soil type, and under similar environmental conditions. The improved growth in this area over that of the unfertilized area is probably attributable to drainage resulting from a slightly raised elevation and greater depth to the fine-textured acid subsoil. Trees sampled in this area had the same diameters as fertilized trees.

Hereafter, trees receiving fertilizer will be termed fertilized; those receiving only lime will be termed unfertilized (mill waste did not affect growth); and trees from the adjacent plantation will be referred to as the control.

Tree Selection

Six, quarter-acre square plots were established, two in each area. Diameters of every tree within these plots were measured and recorded on a grid sheet to establish tree location. Using these measurements, trees were grouped into three diameter classes: (1) small, 6.9 inches; (2) medium, 7.0 to 9.0 inches; and

(3) large, 9.0 inches. Ten sample trees were randomly selected from the fertilized and control areas by diameter class in a ratio of 3:4:3. Since all trees in the unfertilized area were less than 6.9 inches DBH, five trees were randomly selected in each of the unfertilized plots.

Tree Measurement

Trees were felled at groundline, sectioned (fig. 1), and measurements recorded. Wood disks removed at each point of sectioning were 4 inches long except those in the upper crown, which were 6 inches long to assure adequate sample material. Tree size limited the number of sections taken from unfertilized trees to those from the base, 4.5 feet, 8.0 feet, crown base,[4] and 1/2 crown. Disk measurements included: (1) Diameter outside bark, (2) diameter inside bark, (3) green weight without bark, and (4) green volume (by water displacement). Disks were dried to a constant weight at 65° C., then reweighed.

Double bark thickness was calculated for several stem positions by difference between outside and inside bark diameters (fig. 1). Absolute form quotient[5] was chosen as the most appropriate form variable for evaluating tree taper since it is unaffected by differences in bark thickness and tree height (Avery, 1967). Specific gravity values were obtained from the dry weight-green volume ratio of whole wood disks.

Bolt volumes were calculated using Smalian's formula and inside bark diameter measurements. Terminal section volume was calculated using the cone formula. Total tree volume was obtained by summation of these portions. Bolt dry weights were obtained by applying the average dry weight-green volume ratio from the top and bottom of each bolt to the bolt volume. Tree dry weights were obtained by summation.

Wood bolts from the basal 4.5-foot and 12- to 16-foot portion of sample trees were sent immediately to the Forest Products Laboratory, Madison, Wis., for analysis of certain anatomical properties and kraft pulping quality. Wood specific gravity, percent summerwood, growth rate, kraft pulping, and handsheet properties were obtained according to TAPPI procedures.

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[4] Crown base is defined as a point 2.0 in. below the first fully developed whorl of foliage-bearing branches.

[5] Absolute form quotient equals $QA_{ib} = \left(d_{\frac{h-4.5}{2}} \middle/ d_{4.5} \right)$ where $\underline{d}$ is diameter inside bark.

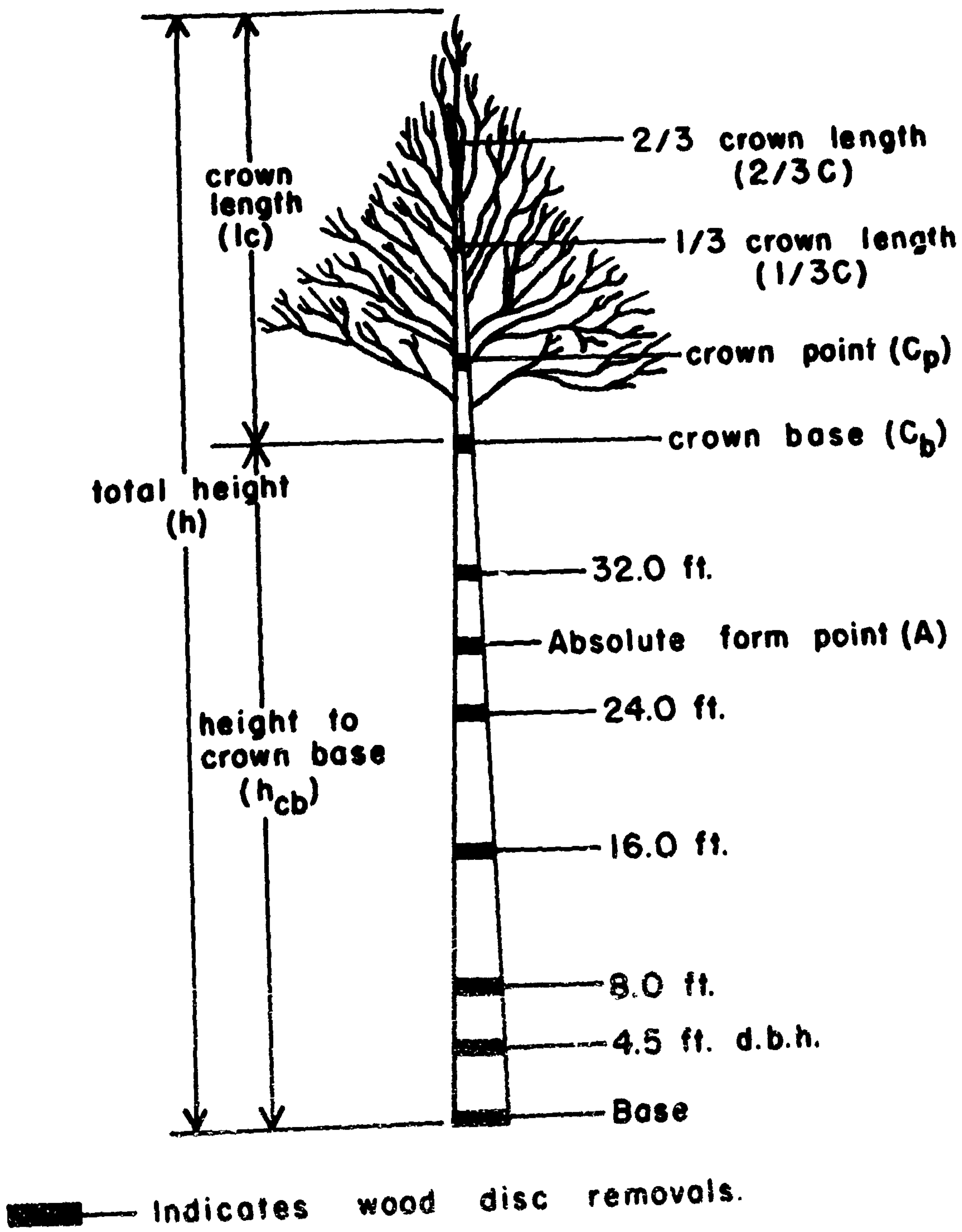

Figure 1.--Diagrammatic representation of tree sampling technique.

Statistical Procedures

Appropriate data were subjected to statistical analysis following procedures of Steele and Torrie (1960). Covariance analysis to detect differences between slopes or intercepts of two regression equations were by the methods of Snedecor (1956).

Results

Bark Thickness

The effect of fertilization on bark thickness was tested by analysis of variance. Trees from all diameter classes were compared from the fertilized and control area. A separate analysis was used to test for bark thickness differences among all three areas using only trees from the smallest diameter class from the control and fertilized area and all trees from the unfertilized area.

Bark thickness varied according to treatment, stem position, and diameter class, but neither the treatment X diameter nor the treatment X position interactions were significant. However, preliminary plotting of the data indicated that, within a given diameter class, mean bark thickness at some stem positions was consistently higher for control trees than values obtained from either the fertilized or unfertilized trees. For this reason average bark thickness is presented by treatment and stem position (tables 1 and 2).

Bark thickness at all stem positions above 8 feet was somewhat decreased by fertilization. The greatest differences occurred in the region of the stem just below crown base. In both tests, bark thickness in this region was found to be significantly decreased by fertilization, using Duncan's multiple-range test procedure.

Stem Form

To test whether fertilization affected the ratio of DBH to some diameter higher up the bole, absolute form quotients were analyzed statistically. Treatment, diameter classes, or their interaction were not significantly different (table 3). However, variation among trees treated alike was large and sample size was rather limited for this test (10 measurements per treatment). A difference of at least 0.036 units would be needed to detect a $Q_{A_{ib}}$ change due to treatment (e.g. a form class change from 70 to 73.6 for example).

Wood Specific Gravity

Wood specific gravity was examined from sections of all sample trees in the fertilized and control areas. A separate analysis was conducted on the small diameter class trees from all three areas. No significant differences in wood specific gravity due to treatment were detected in either analysis. Stem position

Table 1. Average double bark thickness by treatment and stem position for fertilized and control trees.

Treatment	Stem Position[1/] Base	4.5 ft.	8 ft.	16 ft.	24 ft.	A_{f_p}	C_b	C_p	1/3C	2/3C	Treatment average
	(in.)										
Fertilized	1.89	1.44	1.03	0.82	0.64[a]	0.54[a]	0.63[a]	0.50[a]	0.48	0.32	0.83
Control	1.81	1.41	1.13	0.88	0.80	0.69	0.78	0.71	0.60	0.45	0.92
Position average	1.85	1.43	1.07	0.85	0.72	0.62	0.70	0.61	0.54	0.39	0.88$\pm$0.02 in.

[a]Indicates significant differences from comparative control value. Duncan's LDS ($P < 0.05$) for 2 means = 0.15 in.

1/ See Figure 1.

Table 2. Average double bark thickness by treatment and stem position for all trees in the small diameter class.

Treatment	Stem position					Treatment average
	Base	4.5 ft.	8 ft.	Cb	1/2C	
	(in.)					
Fertilized	1.62[a]	1.15[a]	0.77[a]	0.47[a]	0.35[a]	0.87
Control	1.78[a]	1.11[a]	1.02[b]	0.65[b]	0.43[a]	1.00
Unfertilized	1.75[a]	1.07[a]	0.84[a]	0.54[ab]	0.31[a]	0.90
Position average	1.73	1.09	0.86	0.55	0.34	0.91 $\pm$ 0.03 in.

[a]All values within positions followed by the same letter are equivalent.

Duncan's LSD for: 2 means ($P < 0.05$) = 0.17 inches
3 means ($P < 0.05$) = 0.18 inches.

Table 3. Average absolute form quotient (i.b.) by diameter class and treatment.

Diameter class	Fertilized	Control	Diameter class average	Confidence interval (P 0.05)
Small	0.71	0.69	0.70	± 0.034
Medium	0.66	0.70	0.68	± 0.029
Large	0.67	0.66	0.66	± 0.034
Treatment average	0.68	0.68	0.68	± 0.018

was highly significant in both tests. Diameter class and treatment X diameter class interaction for the fertilized versus control comparison were also highly significant. Average specific gravity by treatment, diameter class, and stem position are presented in figures 2 and 3.

Within diameter classes, the greatest difference in wood specific gravity was found in the basal portion of the largest trees, upper crown of trees in the medium class, and both these locations in small trees. However, only the base section of the large trees and the positions in the upper two-thirds of the crown of trees in the small-diameter class were significantly different using Duncan's multiple-range test. These differences probably account for the significant treatment X diameter class interaction.

There is no apparent explanation for the increased specific gravity in the upper portion of the small fertilized stems (fig. 2) unless this increase is related to the somewhat suppressed condition of these trees. Specific gravity varies greatly within the stem due to its correlation with summerwood percent (Spurr and Hsiung, 1954). The formation of summerwood within any stem position is thought to be primarily controlled by the position's proximity to the tree crown (Larson, 1969). For this reason, average specific gravity was plotted by stem position as a percent of total height (fig. 4). When the data were adjusted for relative heights, there were no significant differences in any of the specific gravity values within positions.[6]

Wood Properties and Pulp Quality

Growth rate of the smallest fertilized trees was much greater than that of the comparable unfertilized trees according to the analysis by the Forest Products Laboratory. Yet little difference in growth rate was apparent in trees representing the larger two diameter classes (table 4). Specific gravity of the three small fertilized trees was considerably less than that for small unfertilized trees. Larger trees from control area appeared to have wood of higher specific gravity although differences were not as great as in the smallest trees.

The percent summerwood trend did not show the same pattern at both sampling positions. In the butt logs the amount of summerwood was lower in the fertilized trees. However, at the 12- to 16-foot level, this trend is reversed in trees in the larger two diameter classes. This implies that the amount of summerwood response to fertilization is not the same at all heights in any particular growth increment sheath, but rather more possibly expressed at lower levels in the tree.

Results of kraft pulping studies (table 5) with mixed samples show no important differences in yield. A comparison of the pulp from the 12- to 16-foot sections of the fertilized trees with that of the 12- to 16-foot sections of the unfertilized and control trees, which have about the same quantity of summerwood, shows that the pulp from the treated trees has better strength in all properties and

[6] Variance from Duncan's multiple-range test was obtained by combining the residual variances from both analyses of variance on specific gravity.

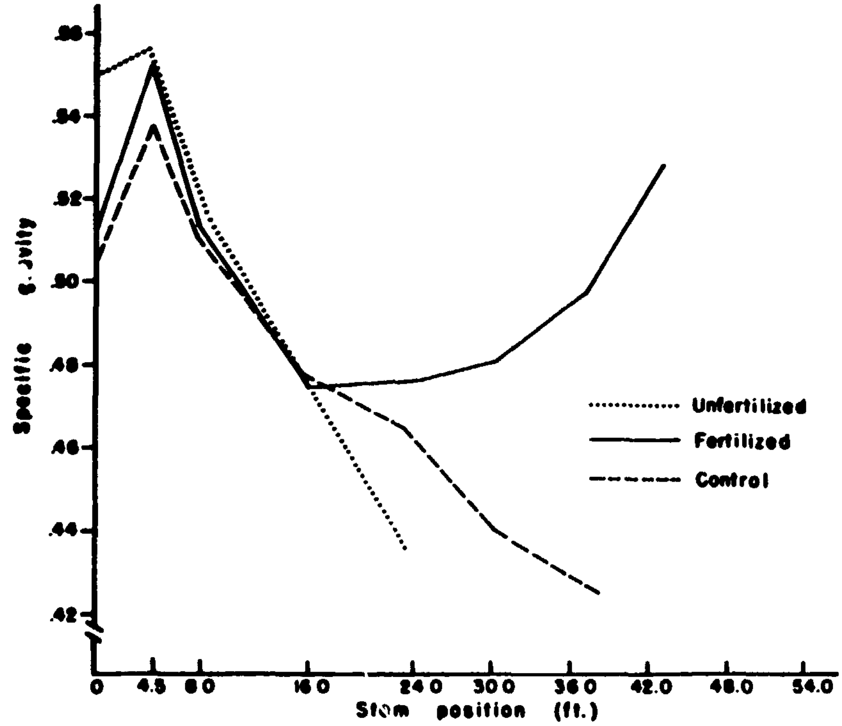

Figure 2.--Specific gravity by stem position for trees from the small diameter class.

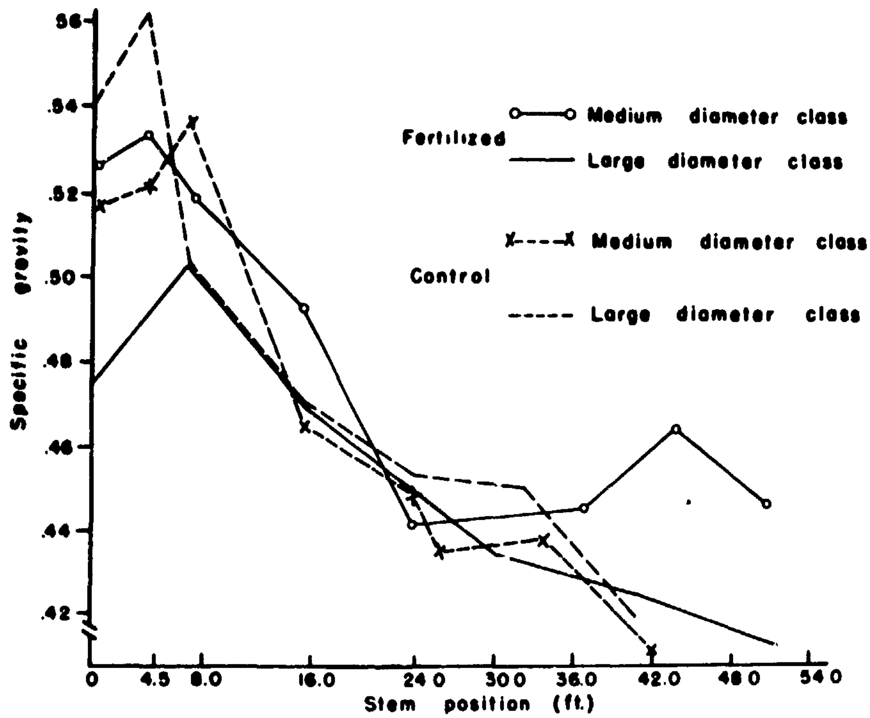

Figure 3.--Specific gravity by stem position.

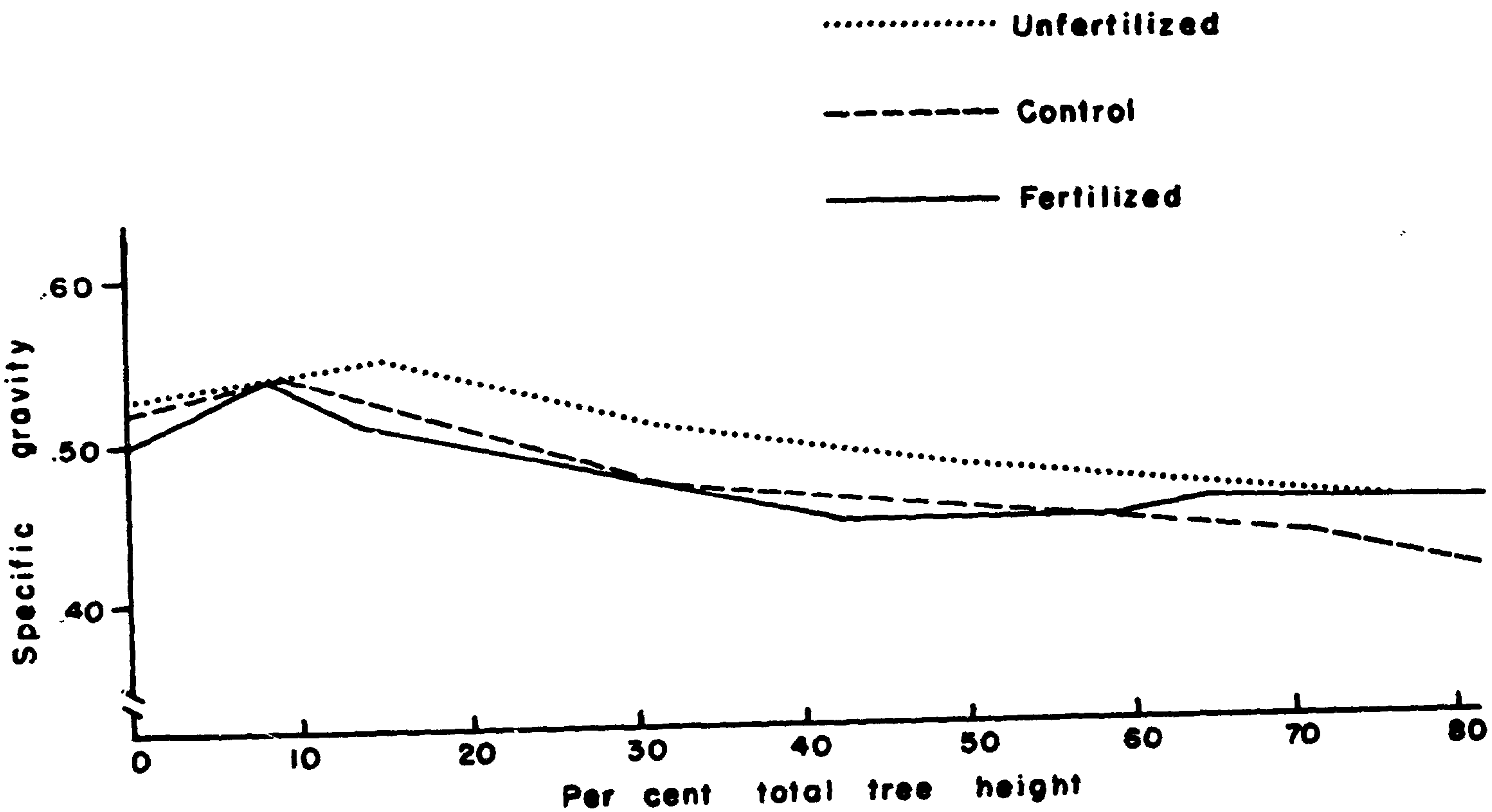

Figure 4.--Specific gravity by percent total height.

Table 4. Anatomical properties of slash pine wood samples by diameter class, treatment, and stem position.

Diameter Class	Tree section 0-4.5 ft. Fertilized	0-4.5 ft. Unfertilized[b]	12-16 ft. Fertilized	12-16 ft. Unfertilized[b]
	Rings/inch			
Small	5.28	6.22	5.33	6.12
Medium	4.17	4.00	4.41	4.14
Large	3.02	3.17	2.87	2.85
	Specific gravity			
Small	0.479	0.599	0.438	0.543
Medium	0.479	0.543	0.438	0.482
Large	0.499	0.546	0.431	0.487
	Percent summerwood			
Small	42.2	56.2	26.7	37.9
Medium	42.4	50.7	35.2	34.3
Large	48.6	52.4	30.6	28.5

[a]Determinations made by personnel of the Forest Products Laboratory. U.S.D.A. Forest Service, Madison, Wisconsin, 53705.

[b]Samples from the smallest diameter class came from the unfertilized area only. Samples in the other classes came only from the control area.

Table 5. Average anatomical properties and kraft pulping of slash pine.

Tree sections	Average anatomical properties			Pulping[a]				
	Average summer-wood	Average growth rate	Average specific gravity[b]	Black liquor NaOH (Na_2O)	Black liquor Na_2S (Na_2O)	Yield[c] Total	Yield[c] Screen-ings	Kappa No.
	Pct.	Rings/in.		G/l	G/l	Pct.	Pct.	
			Unfertilized[d]					
Bases	53.1	4.50	0.562	8.9	7.2	47.7	0.3	35.2
12-16 ft.	33.6	4.37	.504	8.8	7.1	47.3	.4	33.9
			Fertilized					
Bases	44.4	4.16	.486	9.3	7.0	47.0	.3	32.7
12-16 ft.	30.8	4.20	.436	9.0	7.0	47.4	.6	35.5

[a]Conditions used were 18.0% active alkali, 25% sulfidity, 4-to-1 liquor-to-wood ratio, 90 min. to 170° C., and 90 min. at 170° C.

[b]Dry weight-green volume basis.

[c]Moisture-free wood basis.

[d]Samples from the smallest diameter class came from the unfertilized area only. Samples in the other classes came only from the control area.

requires less beating time. This implies that summerwood fibers of the 12- to 16-foot sections of the fertilized trees are more flexible and have thinner cell walls than those in comparable sections of the unfertilized trees. Apparently the basal section of the unfertilized trees has longer tracheids since the tear factor for unfertilized trees is higher than the tear factor for the equivalent portion of the fertilized trees. This trend is reversed in the 12- to 16-foot section. In general, strength of the pulp handsheets appears related to the amount of summerwood in both the fertilized and unfertilized trees (table 6).

Paper produced from fertilized wood appears to agree with Posey's description (1964); namely, paper of higher density, burst factor, and tensile strength. Based on samples taken from breast height, Posey (1964) detected a reduction in tracheid length due to treatment. Results of this study indicate that a reduction in tear resistance due to shorter tracheids does occur but possibly only in the basal portion of fertilized trees.

Conclusion

Bark thickness appears to be decreased by fertilization within a portion of the merchantable stem but not at breast height. Some of the detected differences may be due to tree size and age. If the differences are real, volume calculation incorporating a standard allowance for bark thickness based on bark thickness at 4.5 feet will result in an underestimation of the actual cubic foot volume of wood produced by fertilized trees. For example, the average fertilized tree (8.2 in. DBH OB; 57 ft. tall) is found to have 1.8% more actual wood volume[7] because its bark thickness was decreased by fertilizer treatment. With 500 stems per acre, this would amount to approximately 0.5 cord per acre. While this error would normally be within the confidence interval for volume estimates from most cruise data, the effect of even this small double-bark thickness decrease (0.3 in. maximum) on volume estimation may be important in a rigorous evaluation of fertilizer responses based on individual trees. Although bark weight reductions were not calculated, the magnitude of the waste problem resulting from debarking indicates further importance of this reduction.

Analysis of the data showed no significant differences in tree form due to treatment. Although sensitivity of this test was less than desired, it does not appear that P fertilization has altered tree taper when taper is analyzed independent of the influences of bark thickness and tree height which were influenced by treatment.

Results of this study indicate that while specific gravity trends may be altered due to fertilizer treatment, merchantable wood with reduced specific gravity would be harvested mainly from the basal portion of the largest trees. Although differences exist at upper positions within the merchantable bole, they were slight. Forest Products Laboratory analyses indicate no important difference in yield

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[7] Based on 36-ft. merchantable length to 4.0-in. top DOB.

Table 6. Properties of handsheets[a] made from slash pine.

Tree sections	Beating time at freeness of		Burst factor at freeness of		Tear factor at freeness of		Breaking length at freeness of		Density at freeness of	
	600	400	600	400	600	400	600	400	600	400
	Min.	Min.					M.	M.	G/cc	G/cc
					Unfertilized[b]					
Bases	32	54	64	70	205	181	7,900	8,800	0.65	0.70
12-16 ft.	31	49	75	82	150	138	9,700	10,700	.61	.65
					Fertilized					
Bases	32	52	70	76	191	155	8,500	9,500	.67	.71
12-16 ft.	27	47	80	86	157	140	10,500	11,100	.64	.68

[a]Tested according to TAPPI methods.

[b]Samples from the smallest diameter class came from the unfertilized area only. Samples in the other classes came only from the control area.

based on samples from two stem positions and several pulp quality considerations may be improved by treatment. Because of the large volume increase due to fertilization, differences due to treatment appear miniscule.

In this study where response to fertilization is large, fertilized trees produced almost twice the volume of wood as trees on the best local untreated area (control), though 2 years younger. Fertilized trees produced 6.7 times the cubic volume produced on the unfertilized site (table 7). Reductions in dry weight associated with specific gravity due to treatment were estimated to be between 120 to 255 pounds per cord. However, site amelioration from P application resulted in total dry weight increases of 50,000 to 80,000 pounds of wood. When cubic foot volume production is greatly increased by treatment, any slight reduction in dry weight yield per cubic foot of wood is of little importance. Although application of other nutrients on P to less deficient sites could produce different conclusions, it appears that economic justification of P fertilization can be based primarily on conventional assessment of increased wood volume.

Acknowledgements

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Table 7. Estimated wood volume and dry weight.

Trees	Average volume[a] per tree	Total volume/acre	Average dry wood[b] per cu. ft.	Total dry wood/acre
Acre	Cu. ft. i.b.	Cu. ft. i.b.	Lb.	Lb.
		Fertilized		
489	7.2	3,542.0	30.1	106,584.1
		Control		
490	5.7	1,810.7	31.4	56,843.4
		Unfertilized		
482	1.1[c]	525.4	32.9[c]	17,264.0

[a]Based on local volume equation. $V = -0.01053 X + 0.001914 D^2h$. (D = DBH OB in inches and h = height in feet.)

[b]Based on local dry weight equation. $W = 9.8854 + 0.05489 D^2h$.

[c]Average from a 10-tree sample.

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* * *

Gordon--Iowa State--You mentioned the typical appearance of the foliage on the deficient trees. Do you have any data on foliar response to fertilization?

Gooding--Yes. It was taken in this particular stand and the foliage content is phosphorus deficient by the evaluations we use. If I recall it, it's approximately 100 parts per million phosphorus deficient. Is that close enough?

Gordon--Did you measure again after fertilization and did you have any data on weight response, weight increase in foliage, or any data of that sort?

Gooding--Yes, I do. We have tremendous response in terms of foliage weight. It's hard to make a comparison between stands like these where you have this tremendous increase in growth. Also it is hard to tell whether the response is due because you improved the site or because you have applied feed. Would there be a differential between the two? Seems to me that all we've done here is improve site. There's no difference if we look at a site index 80 stand, we'd have the same foliar weight, for example, as we would in the fertilized stand.

Lawrence, Champion Papers--Would you say again what your distinction was between control and unfertilized?

Gooding--The control was the 17-year-old plantation that had never received any type of treatment whatsoever. The unfertilized stand received 2 tons per acre of millwaste liming material at planting, disked into the soil.

Lawrence--On those yields of wood per acre, what was the age level?

Gooding--On 17-year-olds in the control stand, and 15 years old in the unfertilized stand.

RESPONSE IN GROWTH AND WOOD PROPERTIES OF AMERICAN SYCAMORE

TO FERTILIZATION AND THINNING

by

J. R. SAUCIER[1]

A. F. IKE[2]

Abstract

The growth response and wood properties of 7-year-old sycamore to nitrogen fertilization and thinning were measured 2 years after treatment. The results indicated greater response to thinning than to fertilization in both radial growth and wood properties. Specific gravity and fiber length were positively correlated with rate of growth. The proportional volume of fibers, vessels, and rays were unaffected by either treatment.

Introduction

In 1967 we examined a 7-year-old planting of sycamore (Platanus occidentalis L.) that had received various fertilizer treatments in its first growing season. The results (Saucier and Ike, 1969) indicated practically no differential response in specific gravity, fiber length, and proportional volume of fibers, vessels, and rays for 3 years following fertilization. However, diameter and height growth of the trees were significantly influenced by nitrogen, potassium, and phosphorus. The greatest responses were from nitrogen fertilization.

In early 1968 this same plantation was thinned and fertilized with nitrogen. We used a randomized split-plot study design with three levels of fertilization and two levels of thinning. We assumed that fertilizer treatments applied in 1961 were no longer influencing growth of the trees. In view of results obtained in the earlier study, we wanted to examine the response of sycamore at an older age to verify our conclusion that wood properties of this species remain relatively unchanged by fertilization even though tree growth is accelerated.

Our earlier study was stimulated by the interest in short-rotation coppice management of sycamore (3 to 4 yr.). Some sentiment has been expressed that such rotations may be too short and should be extended to perhaps 10 to 12 years.

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[2]Associate professor, Department of Education, University of Georgia, Athens, Ga. The research was conducted while the junior author was Soil Scientist, Southeastern Forest Experiment Station, USDA Forest Service, Forestry Sciences Laboratory, Athens, Ga.

The purpose of the study reported here was to determine which cultural practice—fertilization or thinning, or their combination—produces the greatest growth response and to determine if any changes in wood properties result from the cultural practices.

Materials and Methods

A description of the site and detailed information concerning the establishment of the plantation have been presented (Saucier and Ike, 1969). The original 54 plots were arranged into nine whole plots. Fertilizer treatments represented the whole plot and thinning treatments the split plot with three replications (fig. 1). The treatments were imposed in early 1968 and the samples were collected after two growing seasons. Ten trees were randomly selected from each of the treatment plots for a total sample of 180 trees. Upon selection, each tree was classified into one of six crown classes. D = dominant; D-CD = dominant-codominate; CD = codominant; CD-I = codominant-intermediate; I = intermediate; and S = suppressed. A measure of stand density was also recorded by indicating the number of neighbors in the adjacent rows surrounding each sample tree. Wood samples consisted of two increment cores taken from the opposite sides of each tree.

In the laboratory, sample preparations and methods were:

1. The bark was trimmed from each core and ring width of each of the four last-formed rings was measured to the nearest 0.01 inch.

2. Beginning at the bark end of the core, we separated rings 1 and 2 intact (wood formed in 1969 and 1968 following fertilization and thinning) from rings 3 and 4 intact (wood formed in 1967 and 1966 prior to fertilization and thinning). The specific gravity of these samples containing two growth rings each was determined by the maximum moisture method (Smith, 1954).

3. One core from each tree was used to determine fiber length. The two samples from a single core (rings 1-2 and 3-4) were cut into small pieces and macerated separately according to the method of Franklin (1946) Fifty whole fibers from each sample were measured with a graduated "bull's-eye" using the selection technique described by Hart and Swindel (1967).

4. The second core from each tree was used to estimate the proportional volume of fibers, vessels, and rays. The samples (rings 1-2 and 3-4) were embedded in paraffin and cross sections 15 microns thick were cut on a rotary microtome. The sections were stained with safranin and fast-green and permanently mounted on glass slides.

The proportional volume of fibers, vessels, and rays was estimated in each ring along a 4-millimeter transect in the center of each ring. Measurements of each tissue type were accumulated along the transect on separate micrometers of an integrated stage, and the percentages of each tissue type were calculated from these measurements.

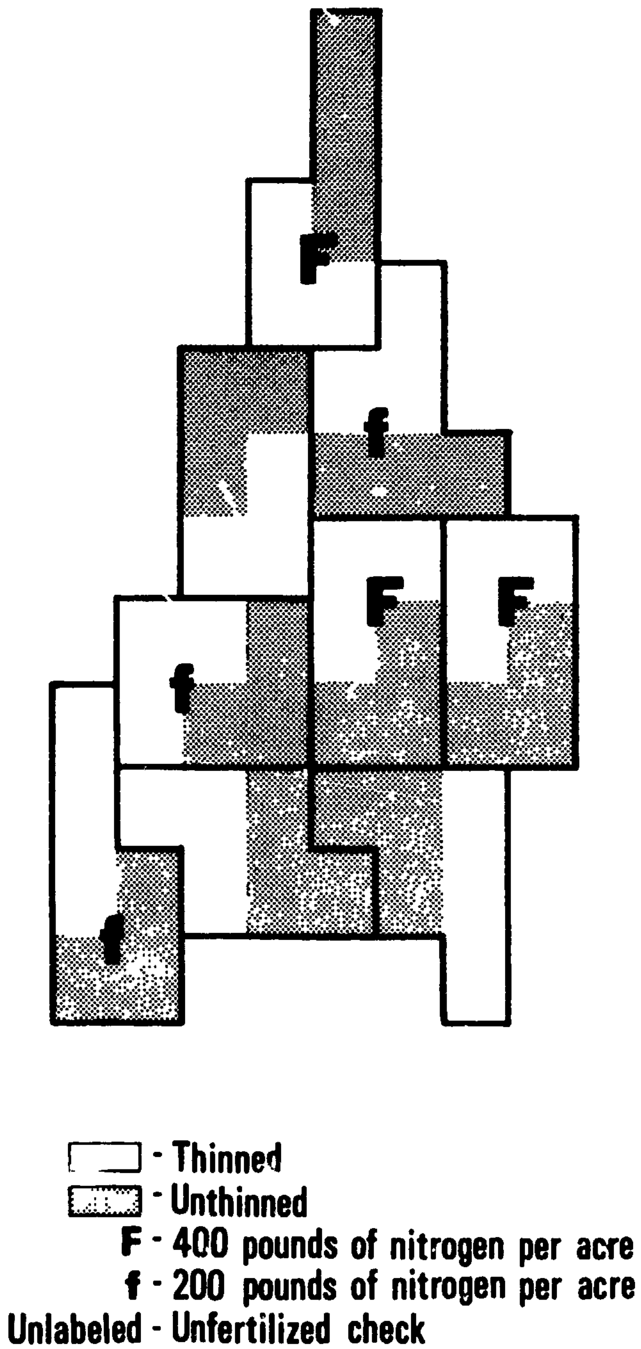

Figure 1.--Plot layout and treatment arrangement.

Results

Radial Growth

Originally we planned to adjust treátment means by covariance analysis based on the values of each property for the 2 years prior to treatments. This analysis proved to be of little value, but the covariates of crown class and stand density (number of neighbors) were worthwhile. For example, radial growth as indicated by ring width measurements was highly correlated with crown class (fig. 2). When the treatment means were adjusted for the effects of crown class, thinning provided a significant increase in ring width but fertilization did not:

Fertilized	Thinned	Unthinned	Mean
	----Inches ring width-----		
0 lb. N per acre	0.19	0.17	0.18
200 lb. N per acre	.18	.17	.18
400 lb. N per acre	.23	.14	.18
Mean	.20	.16	.18

Specific Gravity

This property, like radial growth, was influenced by crown class (fig. 2) and also by the covariate stand density (fig. 3) where the relationship between ring width and specific gravity is seen to be influenced by stand density as it is with crown class (fig. 4). When the effects of both these variables were removed by covariance, neither fertilizer nor thinning treatments were significant:

Fertilized	Thinned	Unthinned	Mean
	-----Specific gravity-----		
0 lb. N per acre	0.396	0.384	0.390
200 lb. N per acre	.385	.386	.386
400 lb. N per acre	.392	.390	.391
Mean	.391	.387	.389

The highest specific gravity values are those for dominant individuals free from dense competition.

The use of stand density as a covariate should be explained at this point. It is, of course, not independent of the thinning variable, since number of neighbors is in fact reduced by thinning. However, because the sample trees were selected randomly, there was an admixture of stand densities for individual trees across both the thinned and unthinned plots. For example, there were several suppressed trees from thinned plots that had as many as 6 to 7 neighbors, and thus, they tended to wash out the true effects of thinning. In retrospect, the variable of stand density is in fact a better measure of thinning than the measure we now have

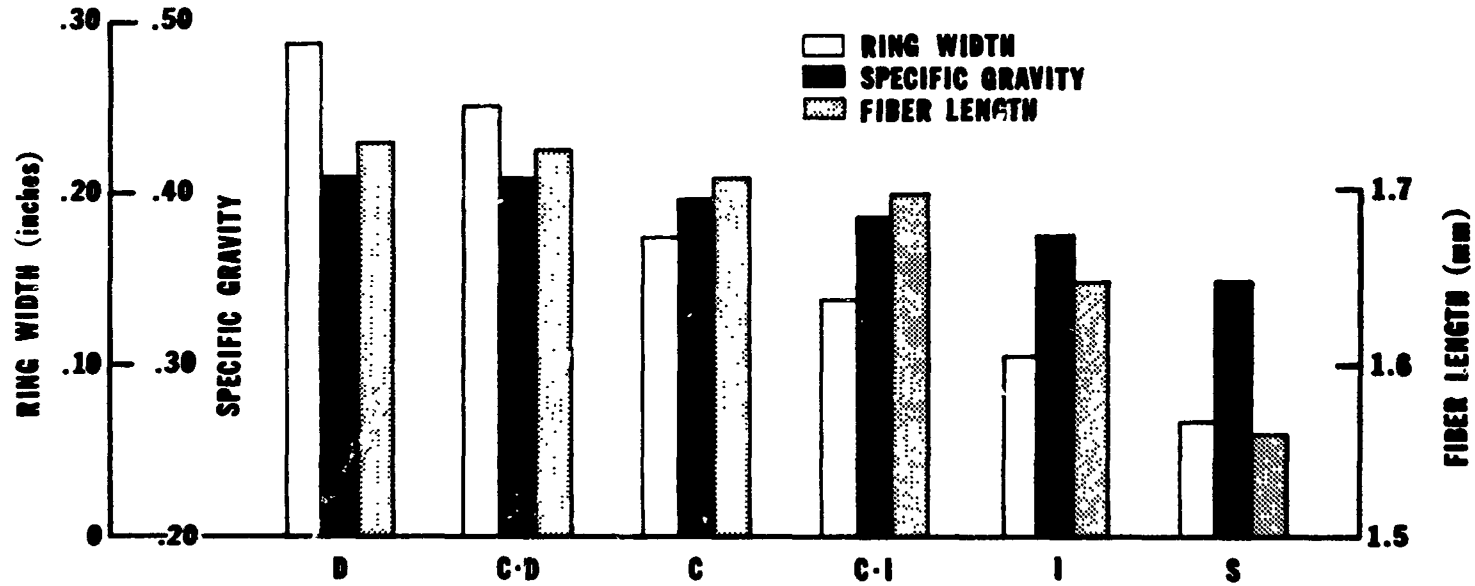

Figure 2.--Histogram of ring width, specific gravity, and fiber length for the six crown classes.

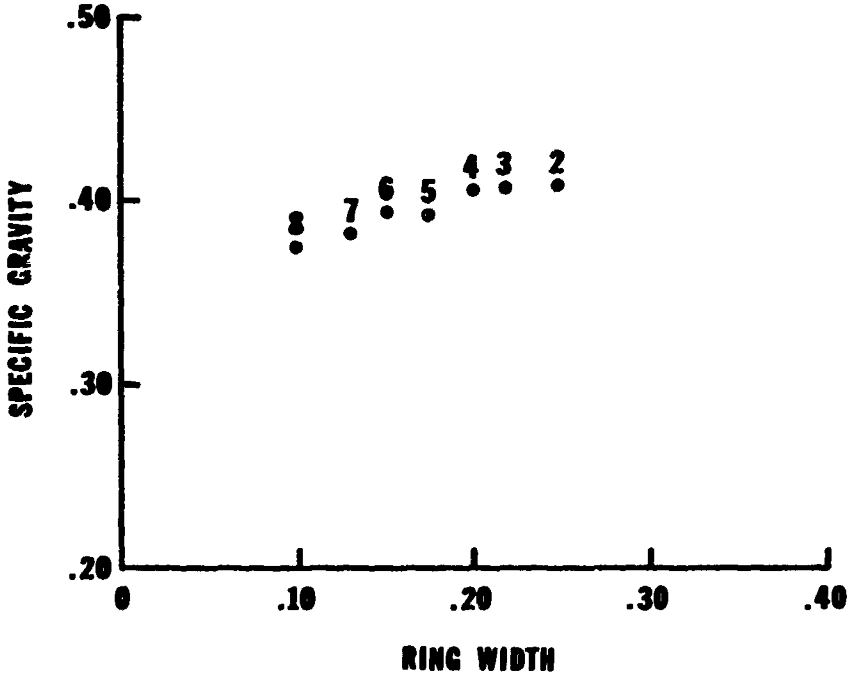

Figure 3.--Effect of stand density (number of neighbors) on the relationship between ring width and specific gravity.

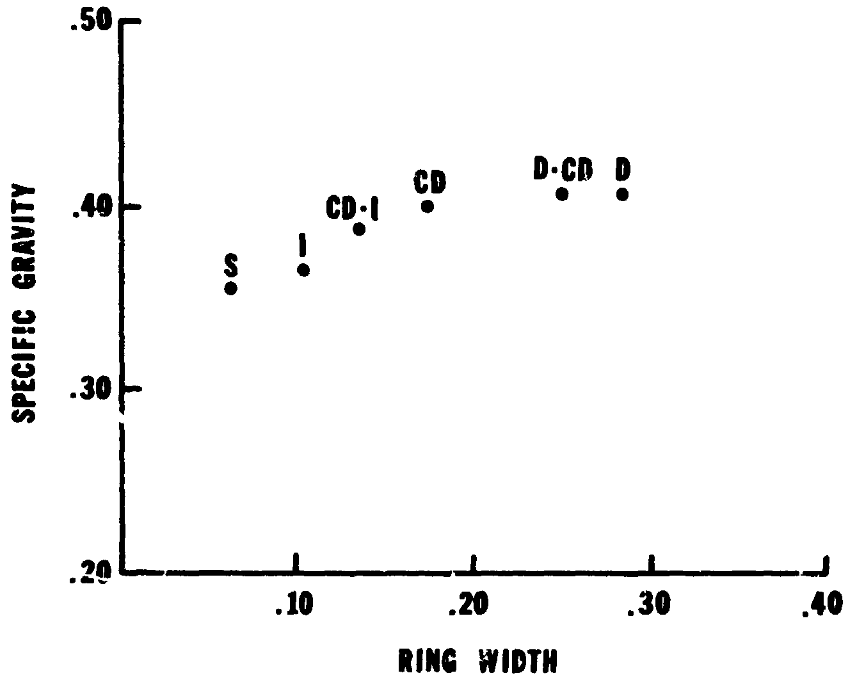

Figure 4.--Effect of crown class on the relationship between ring width and specific gravity.

of thinning treatment, and samples should have been stratified on the basis of this variable. However, since we did measure this variable, its effect was not lost and therefore provides a better measure of thinning--whether naturally occurring or imposed--than that which we call thinning treatment. The effects of both crown class and stand density are seen clearly in table 1 for the three properties of ring width, specific gravity, and fiber length.

Fiber Length

Fiber length is a relatively stable wood characteristic of sycamore. Most values fell between 1.50 and 1.80 millimeters, but ranged from 1.25 to 1.90. Fertilization and thinning treatment means after adjustment for crown class and stand density are presented:

Fertilized	Thinned	Unthinned	Mean
	-----Fiber	length,	mm.----
0 lb. N per acre	1.75	1.69	1.72
200 lb. N per acre	1.67	1.62	1.65
400 lb. N per acre	1.74	1.67	1.70
Mean	1.72	1.66	1.69

Thinning does tend to increase fiber length slightly, but fertilization has no detectable and consistent influence.

Like ring width and specific gravity, fiber length is influenced by crown class and stand density but to a lesser degree. Reduction in fiber length occurs when strong competition reduces growth rate to a value around the 0.10-inch ring width found in those trees classed as intermediate and suppressed (fig. 1) and stand densities of seven and eight neighbors (fig. 5).

Porportional Volume--Fibers, Vessels, and Rays

The property of tissue composition was unaffected by thinning or fertilizer treatment. The proportional volume of fibers, vessels, and rays averaged 54%, 14%, and 32%, respectively. The variation in treatment means was very narrow, ranging from 52 to 56 for fibers, 12 to 16 for vessels, and 30 to 34 for rays which indicates the great stability of this property. The proportion of fibers at age 9 was the same as we had found at age 3 in our earlier study. However, the proportion of vessels and rays had changed from 22% vessels and 24% rays at age 3 to 14% and 32%, respectively, at age 9.

Table 1.--Average ring width, specific gravity, and fiber length by crown classes and stand densities

Crown class[1]	Stand density[2]	Ring width	Specific gravity	Fiber length
	Number	In.	G. per cc.	Mm.
Dominant	3	0.26	0.407	1.73
Codominant	5	.17	.398	1.71
Intermediate-suppressed	7	.09	.375	1.61

[1] Crown classes were combined into 3 broad classes.

[2] Measured by the average number of neighbors.

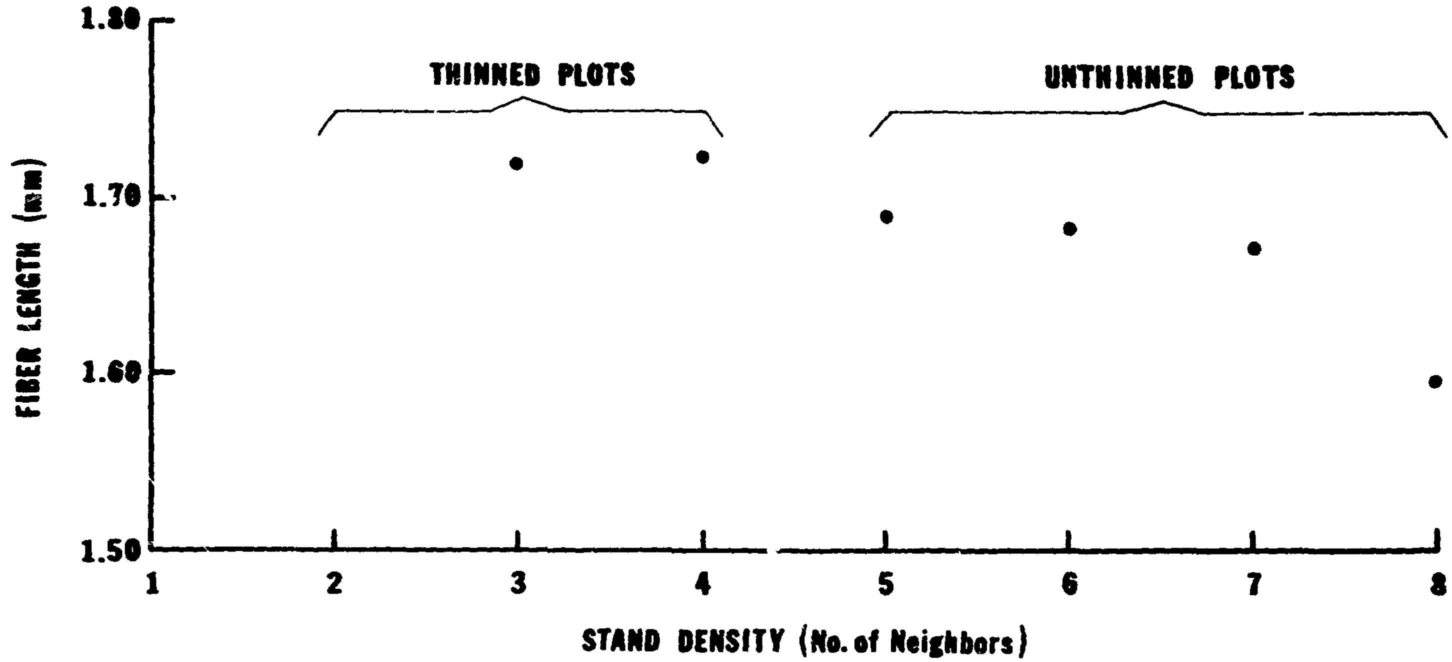

Figure 5.--Average fiber length over the range of stand densities.

Discussion

Fertilization of a plantation of sycamore when it was established produced significant increases in diameter and height growth for 3 years. Although the trees were planted at 8- by 8-foot spacing, crown closure was taking place by age 4, and at age 7 when the present study was imposed strong crown competition was evident. The results of our present study show that the thinning treatment produced a significant increase in radial growth while nitrogen fertilization did not. In other words, growing space was the limiting factor at age 7 and not nitrogen supply. These results suggest that if sycamore is to be grown for longer rotations than the present short-rotation concept of 3 to 4 years, either they must be planted at spacing wider than 8 by 8 feet or receive thinning treatments by at least age 5 to maintain rapid volume growth to ages 10 to 12.

These results support our earlier finding that wood properties are not adversely affected by treatments that increase growth rate of sycamore. In fact, individual trees that expressed dominance, or were freed from competition by mortality or thinning, continued to grow rapidly after age 4 and had the highest specific gravity and fiber length values.

Obviously, the silvicultural scheme used must be adapted to the type product desired to be produced. If the objective is to maximize the production of wood fiber, which, in fact, is the basis for the short-rotation scheme, then harvesting must be done before growth is retarded by stand competition. In the plantation we studied, crown closure occurred at approximately age 4. If the rotation age of such a plantation is extended to 10 years, volume production is not maximized unless commercial thinning can be done at about midrotation.

If trees are initially planted at wider spacings than 8 by 8 feet, then growing space is wasted in the early part of the rotation. A possible scheme for longer rotations would be to begin with trees planted at 4- by 4-foot spacing and to thin every other row at cutting cycles of 3 to 4 years through the final cut at age 12. This scheme, based on these and other data,[3] would possibly provide maximum yield of wood fiber.

Strictly from the wood properties standpoint, the faster growing trees tend to have superior wood properties for pulp; thus the maintenance of fast growth, either through fertilization or thinning, is advantageous.

Summary and Conclusions

A study of the growth response and wood properties of 7-year-old plantation-grown sycamore (spaced 8 by 8 ft.) to nitrogen fertilization and thinning was made. Two years following treatments, increment cores were extracted from 180 trees for response measurements. The results indicated greater response to thinning than to fertilization in both radial growth and wood properties.

[3] Personal communication with Robert G. McAlpine.

The covariates, stand density and crown class, accounted for more variation than the treatment variables of fertilization and thinning. These results indicate that the covariates provided a better measure of thinning effects than the treatment itself because of severe stand competition at age 7 when the treatments were imposed.

The conclusions drawn from this study are:

1. Growing space becomes the limiting growth factor of sycamore after 4 years when planted 8 by 8 feet.

2. After crown closure occurs in sycamore, the greatest growth response is to thinning and not to fertilization.

3. The wood properties--specific gravity and fiber length--are positively correlated with rate of growth of sycamore.

4. Tissue composition, i.e., proportional volume of fibers, vessels, and rays, are unaffected by rate of growth.

5. Extension of the short-rotation sycamore scheme from 3 to 4 years to 10 to 12 years would require thinnings at 3- to 4-year intervals to maximize fiber production.

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* * *

Isebrands, Forest Service--When you're dealing with rapid growth in hardwoods there's a high influence of reaction wood. Have you had any experience with tension wood in these rapid growing situations that you described?

Saucier--I haven't at this time, not in sycamore.

Gordon--Could we take time to show your other two slides about properties?

Saucier--Yes, they're right in line here. Jim Laundrie, would you like to discuss these?

Laundrie, FPL--We pulped these 2-, 3-, and 4-year-old sycamore trees that he was talking about earlier at the 1 by 4 and 6 by 4 spacings. We pulped the whole trees here, excluding the leaves, but it does include the branches and the bark. The yield raised from 39.6 for the 2-year-old 1 by 4 up to 44.1 or 45 for the 4-year-old. We also cooked an older tree from the same area that was 33 years old and again we pulped the whole tree. We have a pulp yield of 47.9. As far as the handsheet properties go, they are much the same whether they are from 2-, 3-, or 4-year olds; however, there is a difference between the pulp made from the young trees and the mature tree. In beating time the older tree takes quite a bit longer to get to 500 freeness. The burst and the breaking length of the young trees are essentially the same as a mature tree. The big difference is in the tear factor, as we get about 20% more tear from the mature tree than we do from the younger tree. Handsheet density of the mature tree is less than the density of the pulps made from the young trees. About the same trends are evident at 300 freeness.

Saucier--I'd like to make one more comment on this. The bark percentage isn't included here, but for the 2-year-old material we used 20% active alkali; this decreased to about 16% for the 4-year-old material. This reflects just the amount of alkali needed to pulp the additional bark in there.

Bengtson, TVA--Joe, early in your presentation you showed a time course of the nitrogen response in sycamore; at another point you commented that at about the third year the ring width was dropping off and suggested that maybe the effect of fertilization was wearing off. I would like to just point out that it's really better to work with basal area in making this type of statement because you're laying down wood. Where you do have response at an early age, you're laying down wood on a larger cylinder. You could have a dropoff in ring width without an actual dropoff in growth expressed as either dry weight or basal area.

Saucier--That's right; I agree with you.

DETAILED DBH DENSITY PROFILES OF SEVERAL TREES

FROM DOUGLAS-FIR FERTILIZER/THINNING PLOTS

by

R. A. MEGRAW[1]

W. T. NEARN[2]

Abstract

Ring-by-ring and within-ring density information developed from X-ray analysis of increment cores is presented for eight fertilized or thinned Douglas-fir trees. Treatment results for these trees are reported in terms of the actual pounds of fiber produced, the average ring densities, and the within-ring distribution of individual fiber densities. Treatment altered the within-ring density distribution but did not reduce average ring density or influence wood density ranking among this group of trees. Implications of these findings and a summary of the X-ray methodology used are presented.

* * *

When first confronted with the question of how wood quality has been affected by siliviculture, one is usually overwhelmed with the multitude of possibilities implicit in the term "quality." The first task facing a commercial enterprise, therefore, is to decide not only which properties are truly relevant to their operation, but which of these few deserves first and greatest attention.

Careful ponderance of these questions will inevitably point to wood density as that characteristic on which priority effort should be concentrated. First, it supplies the parameter needed for a true economic evaluation of forest production; i.e., the actual mass of usable fiber grown per acre. The importance of having yield information in these terms is rising rapidly as timber producers plan for supplying an increasingly fiber-oriented economy. Secondly, when acquired by intensive measurement, density data also provide a very reliable indication of the more important end-use cellular characteristics of wood; namely, cell wall thickness and the relationship between this wall thickness and lumen diameter. Thus, wood density is not only a characteristic property which can be easily measured on a large scale, but also the one which provides greatest leverage on knowledge fundamental to both supply and end-use factors.

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[1]Senior scientist, RDP&E, Weyerhaeuser Company, Seattle, Wash.

[2]Professional specialist, RDP&E, Weyerhaeuser Company, Seattle, Wash.

Intensive density information, arising from a preliminary sampling of several trees from Douglas-fir fertilizer-thinning plots, will be presented and discussed. By "intensive" is meant the measurement of only a small group of cells at a time, as shown in figure 1. This allows both ring-by-ring and within-ring growth and density information to be gathered simultaneously. Not intended as a statistical sampling of plots, this investigative study nevertheless elucidates the within-tree growth and density changes effected on these trees by treatment. It also illustrates the value of having within-ring density information when assessing the effects of cultural treatments in terms of fiber properties.

Experimental Procedure

Two cores per tree from opposite radii at DBH were the starting material for the trees discussed. Eight trees were sampled, two each from plots designated T_oF_o, T_3F_o, T_oF_3, and T_3F_3. "T_o" represents a calibration thinning and was applied to all plots before the 1962 growing season, while "T_3" designates the highest level of thinning, applied in years 1965 and 1968. "F_o" represents no fertilization. Applications of "F_3," the highest level of fertilization, were made in years 1962, 1965, and 1968. Treatments sampled represent the extremes in application levels for the plots concerned. Precise treatment levels and dates are given in table 1.

All cores were equilibrated to 50% R.H. at 70° F., sawed to constant thickness, and X-rayed. The negatives were then traced with a densitometer, and the resulting signal recorded on paper punch tape. From this raw input data as many types of computer output can be obtained as desired, ranging from a single value representing the total mass of fiber produced by the tree, to detailed within-ring density profiles like those shown in figure 11. Figure 2 depicts a graph being plotted by the timeshare computer terminal. A more complete discussion of the analytical techniques used will be published at a later date.

Results

Figures 3, 4, 5, and 6 are graphs of specific gravity and linear mass increase as a function of year for each of the eight trees. These graphs, as with most of those presented, were taken directly off the computer, with the connecting line for gravity and shading for linear mass increase added later to increase visual clarity. The term "linear mass" as herein used is defined as ring density times ring width, thus giving British units of (lb. per ft. sq.). When this quantity is multiplied by ring circumference and height, one gets actual fiber increase in pounds for the year. Since linear mass is not influenced by circumference, i.e. prior growth, it provides a more meaningful between-ring growth comparison for evaluating treatments than does the actual mass increase in pounds.

Figure 1.--A photomicrograph of an X-ray negative from a resawn increment core. The superimposed circle represents the relative size of the densitometer slit, and therefore the relative size of each discrete sampling area. This particular location is ring 1961, core B, tree 66, plot T_oF_3.

Table 1.--Treatment dates and application levels for the trees investigated

Treatment	Type and date applied
T_o	Calibration thinning only in 2/62
T_3	Calibration thinning in 2/62 20% of growth reserved 4/65 20% of growth reserved 2/68
F_o	No fertilizer applied
F_3	Fertilizer applied - 2/62, 4/65, 2/68 Amount: N - 300 lb. per acre P - 150 lb. per acre K - 100 lb. per acre

Plot combinations sampled: T_oF_o

T_3F_o

T_oF_3

T_3F_3

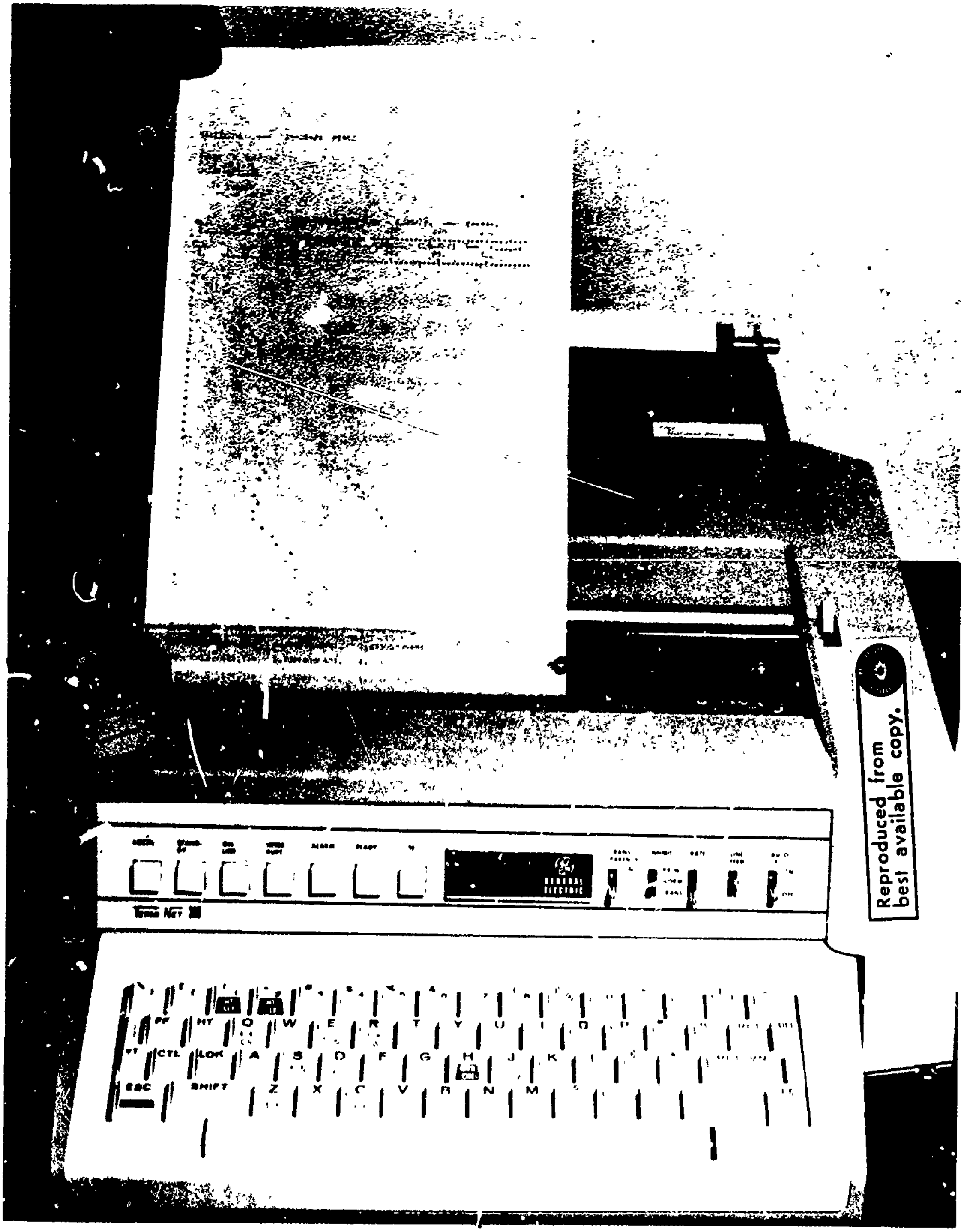


Figure 2.--Timeshare computer terminal with a graph of annual and cumulative mass increase being plotted. Shown on top left of console is roll of paper punch tape containing raw data.

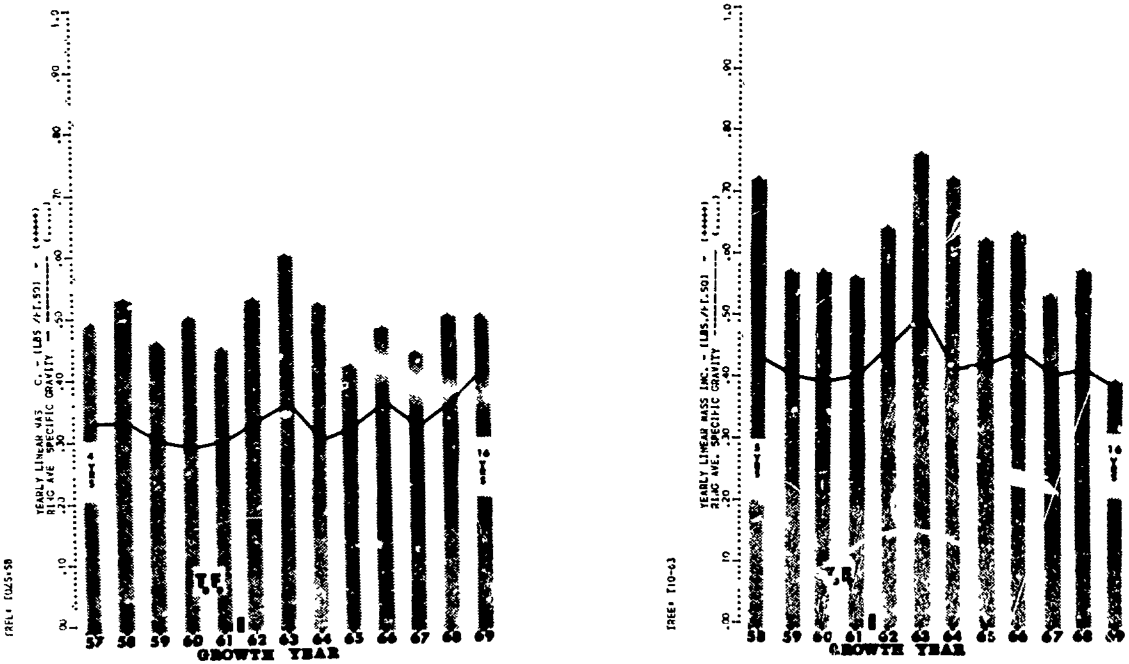


Figure 3.--Yearly linear mass increase (lb. per ft. sq.) and average ring specific gravity plotted as a function of growth year for the two trees from plot T_oF_o. Treatment, consisting of a calibration thinning, is designated by the heavy bar immediately above the horizontal axis.

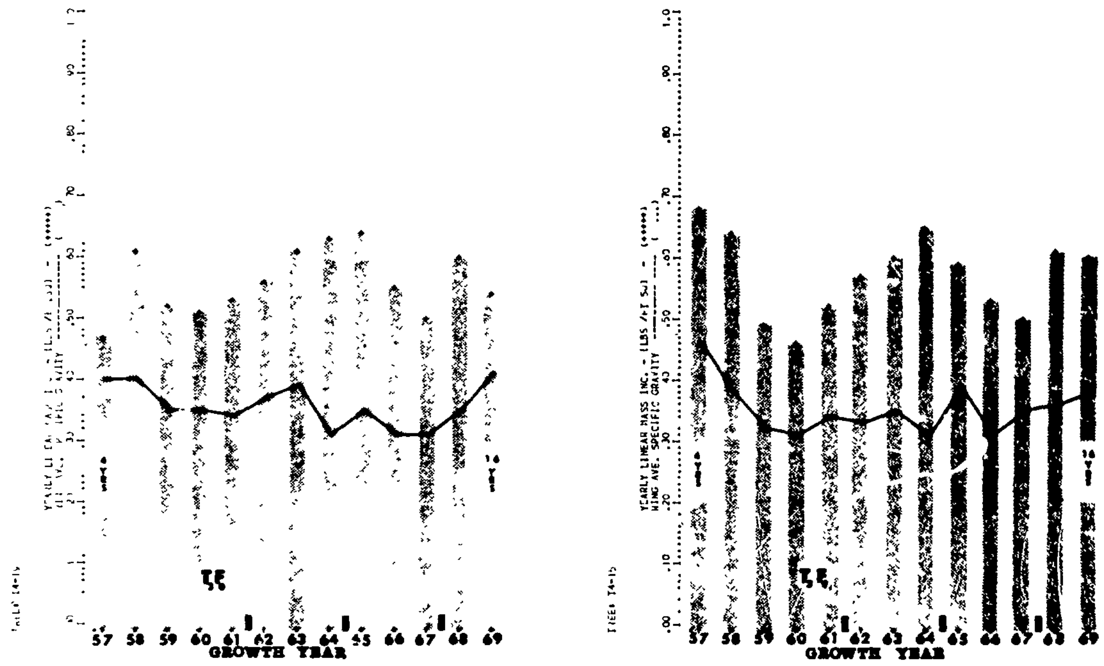


Figure 4.--Yearly linear mass increase (lb. per ft. sq.) and average ring specific gravity plotted as a function of growth year for the two trees from plot T_3F_o. Treatment application (see table 1) is designated by the heavy bars immediately above the horizontal axis.

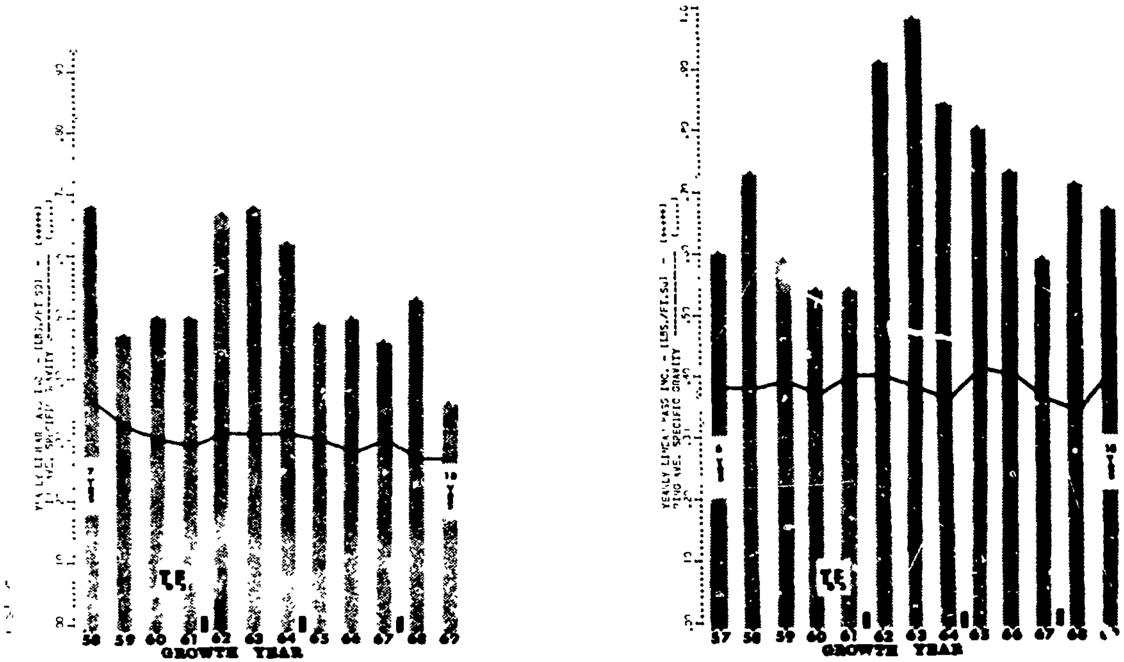


Figure 5.--Yearly linear mass increase (lb. per ft. sq.) and average ring specific gravity plotted as a function of growth year for the two trees from plot T_oF_3. Treatment application (see table 1) is designated by the heavy bars immediately above the horizontal axis.

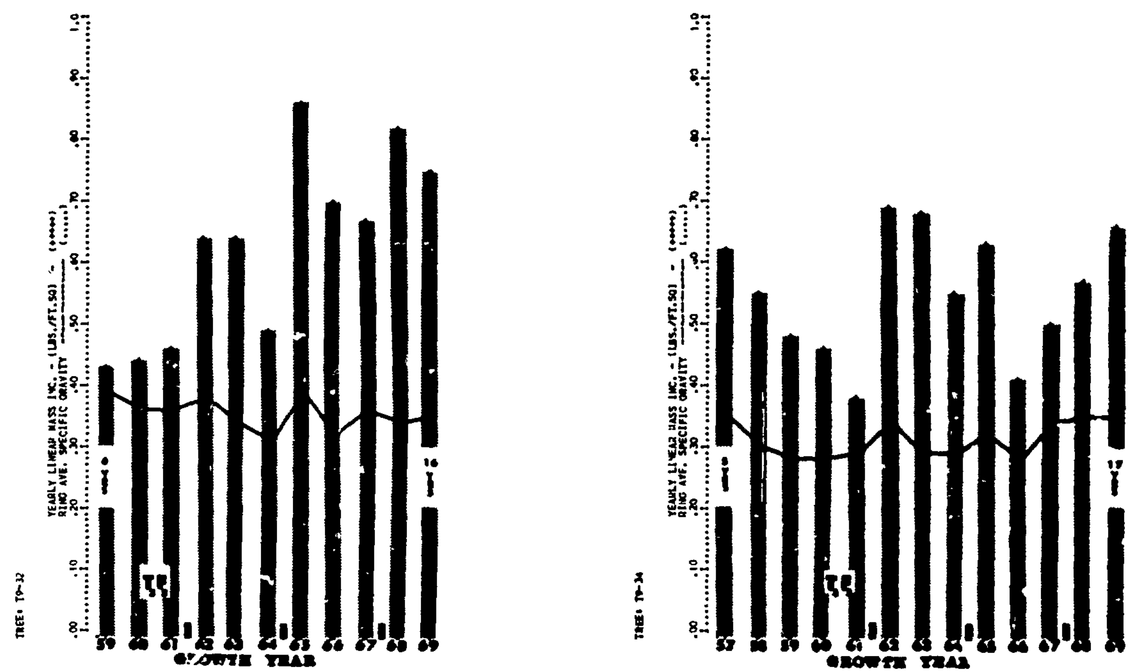


Figure 6.--Yearly linear mass increase (lb. per ft. sq.) and average ring specific gravity plotted as a function of growth year for the two trees from plot T_3F_3. Treatment application (see table 1) is designated by the heavy bars immediately above the horizontal axis.

Respective treatments are identified on the face of each graph, the solid bars designating when these were applied. It is readily apparent in every tree that fiber production was enhanced by the treatment it received prior to the 1962 growing season. Response is also evident but less pronounced for the second and third treatments. Since relatively high levels of treatment were involved, the lessened impact of the latter two applications is only reasonable. A look at the corresponding densities shows that average ring density was not drastically affected by any of the treatments, and in some cases, went up slightly immediately following treatment. This upward trend was particularly true after the first thinning in those trees not fertilized, although the increase was not prolonged.

Thus at first glance, none of these treatments had any real influence on average ring density. A somewhat subtle but nevertheless quite important trend is evidenced, however, when one remembers the influence which age from the pith normally brings to bear on gravity. In the typical Douglas-fir tree shown in figure 7 it can be seen that, after an initial sharp decrease near the pith, the specific gravity begins to rise rather steadily throughout the juvenile period to an age of about 40 years, after which time it levels out. Responsible for this age-density pattern are changes which take place in the relative proportions of earlywood and latewood, and also changes which occur in the average density of each of these two fractions. As figure 8 shows, the earlywood width in this tree rapidly decreased, while latewood width increased for the first few years and then leveled out. The summation of these two widths results in a decreasing total ring width and a relatively lesser proportion of earlywood, producing an increasing trend in overall ring density. Occurring at the same time, as seen in figure 9, is a normal increase in the average gravity of the latewood throughout the juvenile period and, except for an initial 5- to 10-year rapid decrease, an upward trend in the average gravity of the earlywood fraction. While this general age versus density pattern can be found in Douglas-fir almost without fail, the specific timing and magnitude of increase or decrease may be quite different for any two trees, as is illustrated by comparing the tree described in figure 10 with that in figure 7.

The trees in this study were all 16 to 18 years old at DBH, and although those thinned-only are beginning to at least hint at an upward trend in density, there is no indication in any of the fertilized trees that the juvenile wood stage is beginning to wear off. While, as seen in figure 10, some trees do not normally show an increase in density until about this age, after which time density increases quite rapidly, it is highly improbable that all eight of the trees examined would be of this extreme type. Thus, while it is still too soon to be certain, there is definitely an indication that the period of juvenile wood formation is being extended. The explanation for this phenomenon is presumably what physiologists have been saying for a long time--that, since juvenile wood is produced under the influence of the live crown, those practices which increase crown vigor in young trees will also likely prolong the juvenile growth period.

These trees are not yet old enough to determine the actual time-length of this indicated prolongation of lower density juvenile wood production. Specific answers to this question, however, as a function of both site and treatment level, will be of significant importance to the forest manager of the future. Weight conversions from traditional yield tables may have to be altered to compensate for the increase

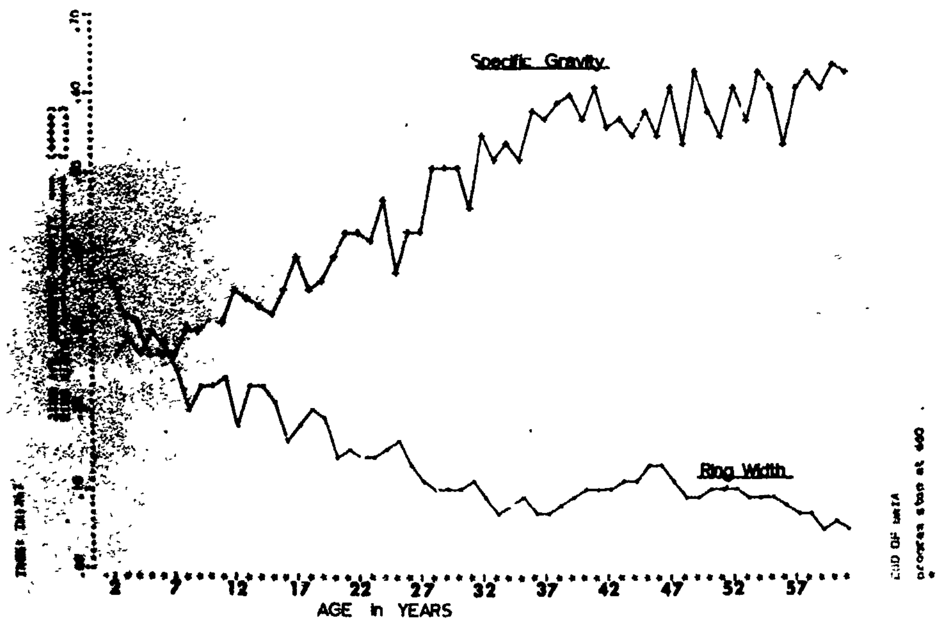


Figure 7.--Typical Douglas-fir tree, trend with age from the pith of average ring specific gravity and ring width in inches. Data obtained by X-ray analysis from an increment core taken at DBH.

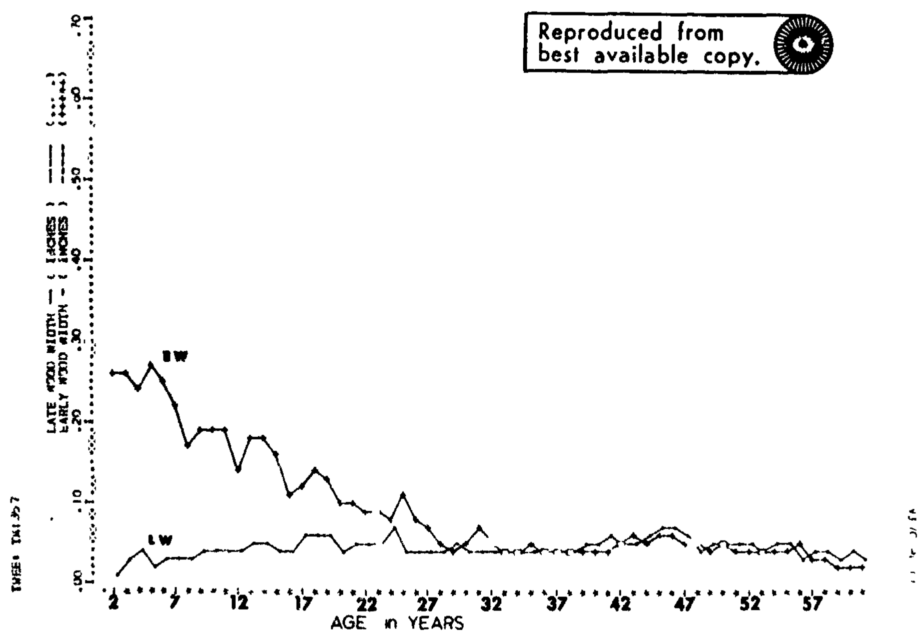


Figure 8.--Width of latewood and earlywood as a function of age from the pith. Same core as represented in figure 7.

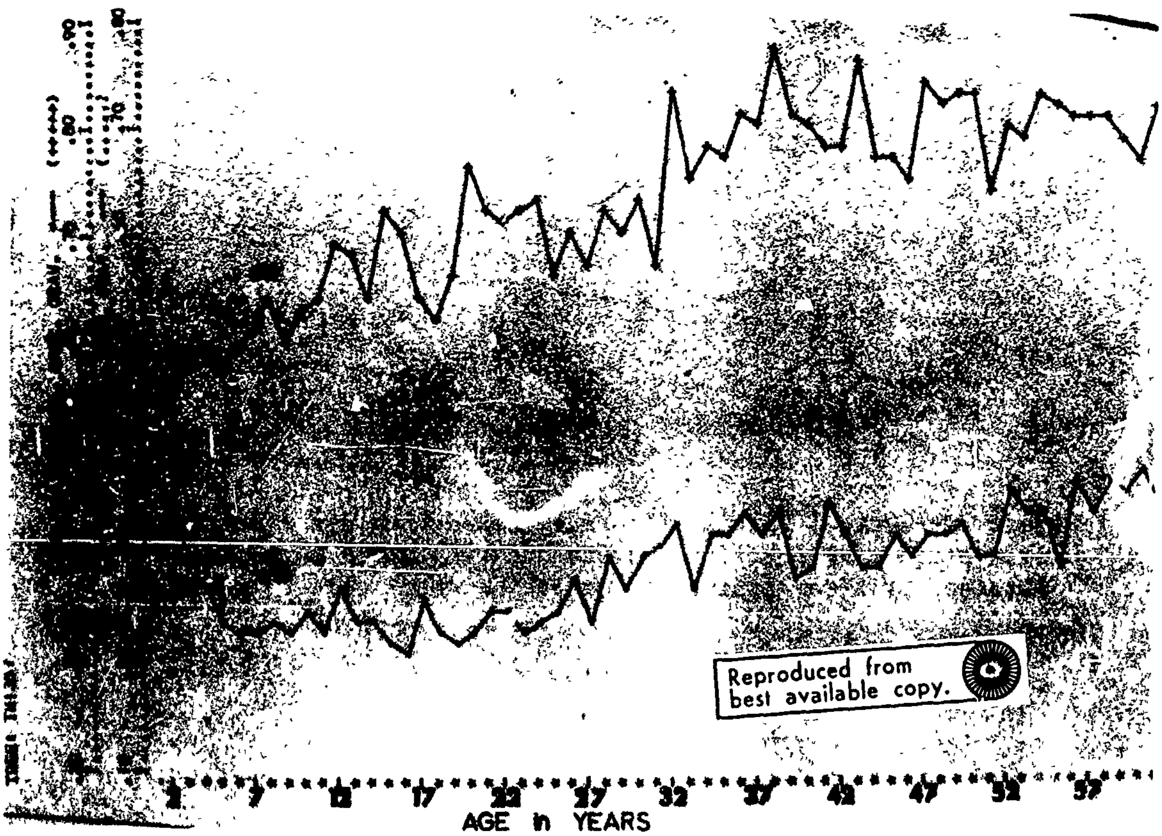


Figure 9.--Douglas-fir tree showing trend with age from the pith of average ring specific gravity and ring width in inches. Same general trends but quite different specific curve shapes are exhibited compared to the tree described in figure 7. Data obtained by X-ray analysis from an increment core taken at DBH.

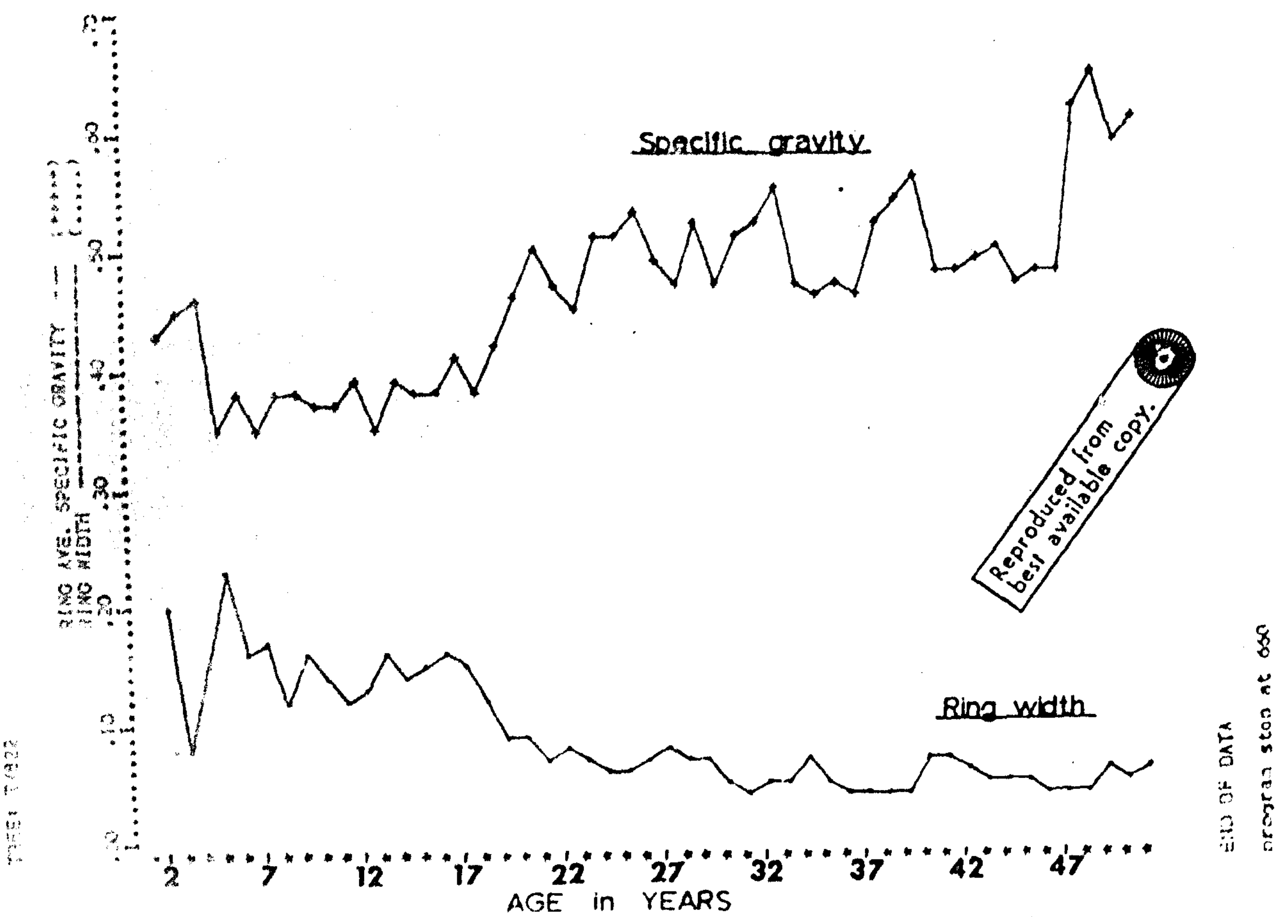


Figure 10.--Average specific gravity of latewood and earlywood fractions as a function of age from the pith. Same core as represented in figures 7 and 8.

in juvenile wood percentage, and rotation age for optimum fiber production may likewise have to be adjusted slightly for heavily fertilized stands.

Change in Within-Ring Density Distribution

It was seen from figures 3 to 6 that the average ring specific gravity was not changed significantly by any of the treatments. This does not necessarily mean that the resulting fiber densities, and therefore type of fibers produced, were unaltered; in fact, they definitely were. Figure 11 shows a computer plot of the density profiles for annual rings 1960 to 1963 for one of the trees from plot T_oF_2, which received calibration thinning plus fertilization just prior to the 1962 growing season. It can be seen that in the 2 years following treatment the maximum fiber densities were distinctly lowered, and considerably more intermediate density wood was formed. This is illustrated quantitatively by the graph in figure 12, which shows that for the two growth rings following treatment the average gravity of the earlywood portion increased and the average gravity of the latewood portion decreased, even though the average for the complete rings remained about the same as for the prior 2 years.

Figure 13 shows the density profiles for all of the years from 1958 to 1969 for the same core described in figure 11. This tendency towards more intermediate density wood was renewed following the refertilization treatments of 1965 and 1968. Shown below this profile is a positive print of the X-ray from which the data were taken. Similarly altered density profiles following treatment were found for the other fertilized trees. The thinned-only trees also exhibited the same phenomenon, but to a lesser extent. It is predicted that this type of wood, with more intermediate density fibers and considerably more overall uniformity, should make excellent pulp. Moreover, the reduction in percentage of very high density latewood cells, which are thick walled, small lumened and stiff, should favorably affect burst factor, breaking length, and other such pulp properties that are enhanced by increased fiber flexibility and conformity.

Importance of Genetics

When a farmer goes to all the trouble and expense of planting, cultivating, and fertilizing his crop, he plants the best seed he can get. This holds equally well for trees. As seen in figure 14, the cross-sectional area at DBH of the two trees from plot T_oF_o is approximately equal (8% different, based on the smaller). Tree 63 has a considerably higher overall specific gravity, however, and has produced over 35% more pounds of fiber during the same period. In figure 15 two trees from the same fertilized plot, T_oF_3, are compared. Again, the areas were only about 8% different, but due to the higher specific gravity of tree 104, this tree produced 40% more actual wood fiber on a weight basis. As is shown in figures 16 and 17, in each case the superior density tree consistently put on both higher density earlywood and higher density latewood.

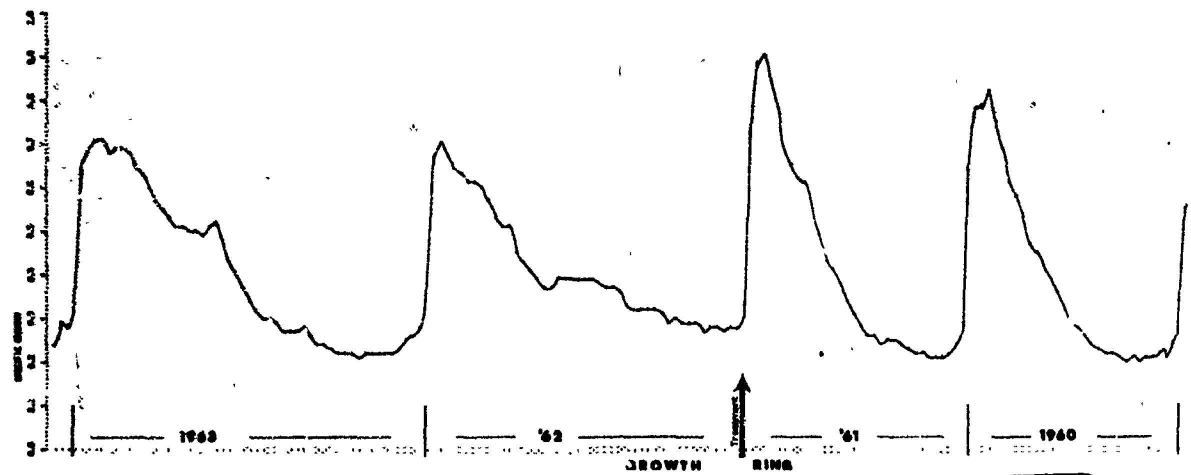


Figure 11.--Within-ring density profiles for two rings before treatment and two rings after treatment: Core 4, tree 104, plot T_0F_3. Calibration thinning and fertilizer were applied during the winter of 1962. Only every second specific gravity sample actually taken has been plotted.

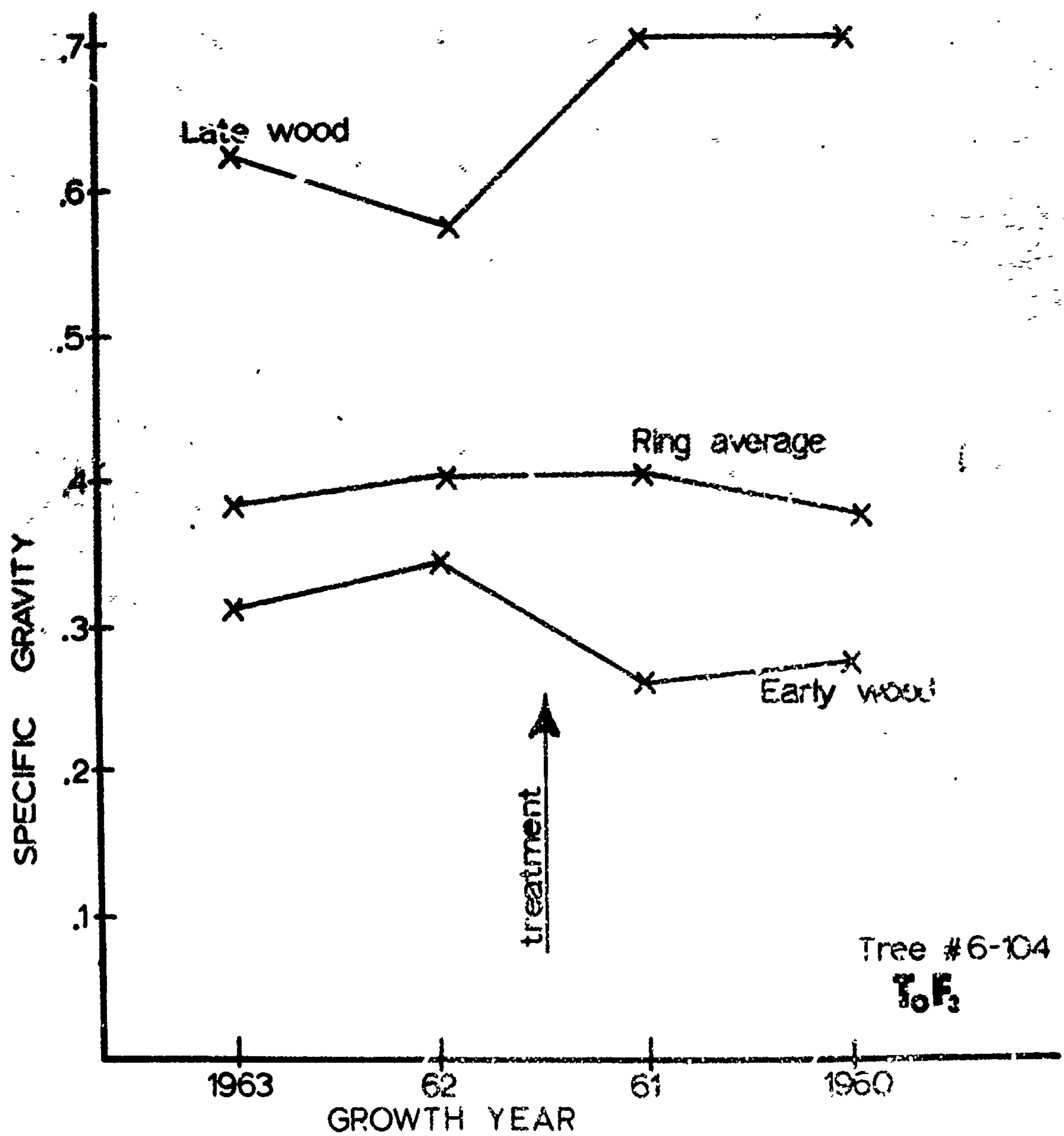


Figure 12.--A specific gravity summary of the same four growth rings illustrated in figure 11. Note that while the overall ring average changed little after treatment, the average specific gravity of the earlywood fraction increased while that of the latewood fraction decreased.

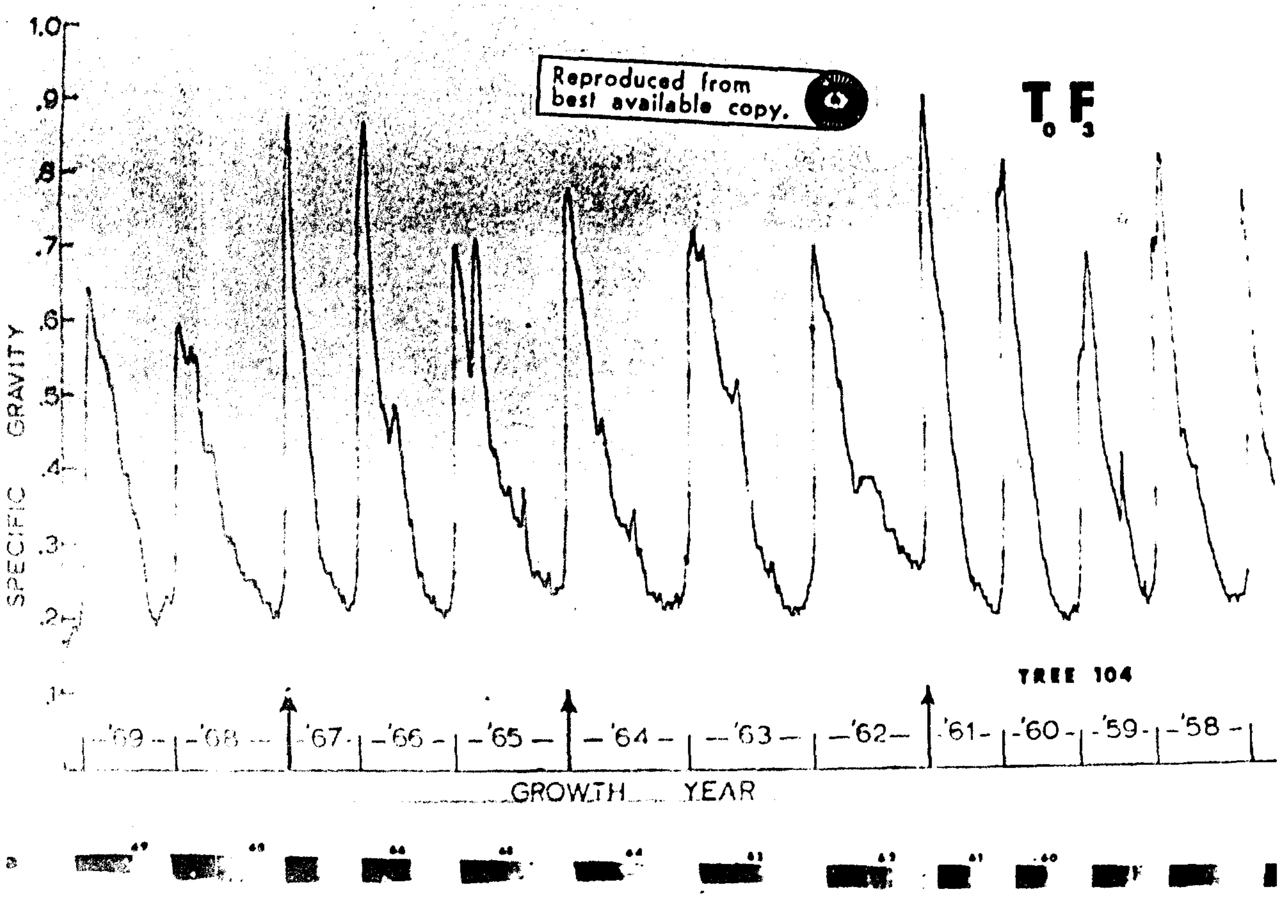
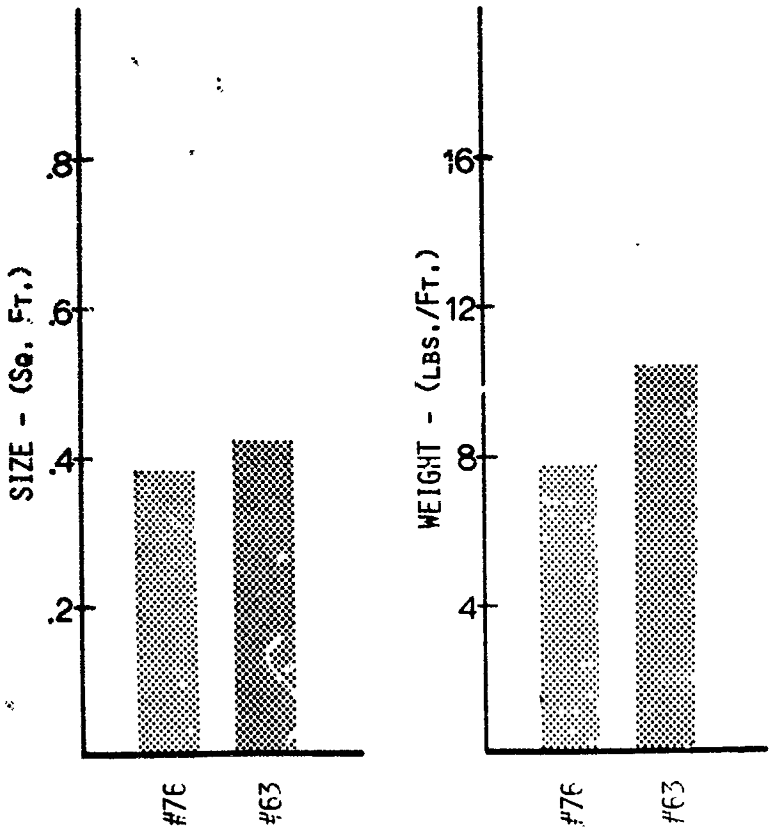


Figure 13.--Density profile of rings 1958 to 1969 for core A, tree 104, plot T_0F_3. Graph was created by a graphic plotter from data stored in the computer. Treatment application is designated by the arrows immediately above the horizontal axis.

Below is an enlarged positive print of the X-ray negative from which the raw data were taken. Note that many of the trends can be seen visually on a qualitative basis.



T_oF_o

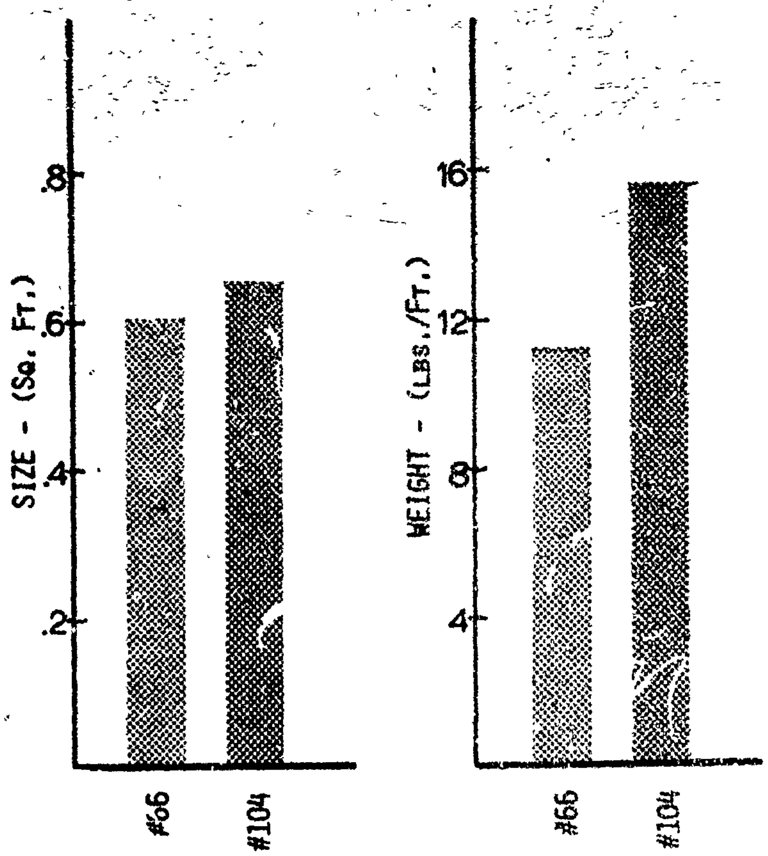
TREE	AVE. SP. GRAVITY (YRS. 59-69)
#76	.33
#63	.41

GROWTH OF TREE #63 RELATIVE TO TREE #76

SIZE: 8% MORE

WEIGHT: 35% MORE

Figure 14.--Comparison of the 1959 to 1969 basal area and weight increases for two trees from the same T_oF_o plot. Trees were untreated except for a calibration thinning in winter of 1962.



T_0F_3

TREE	AVE. SP. GRAVITY (YRS. 59-69)
# 66	.30
#104	.38

GROWTH OF TREE #104 RELATIVE TO TREE #66

SIZE:	8% MORE
WEIGHT:	40% MORE

Figure 15.--Comparison of the 1959 to 1969 basal area and weight increases for two trees from the same T_0F_3 plot. Both trees received fertilization treatments in 1962, 1965, and 1968.

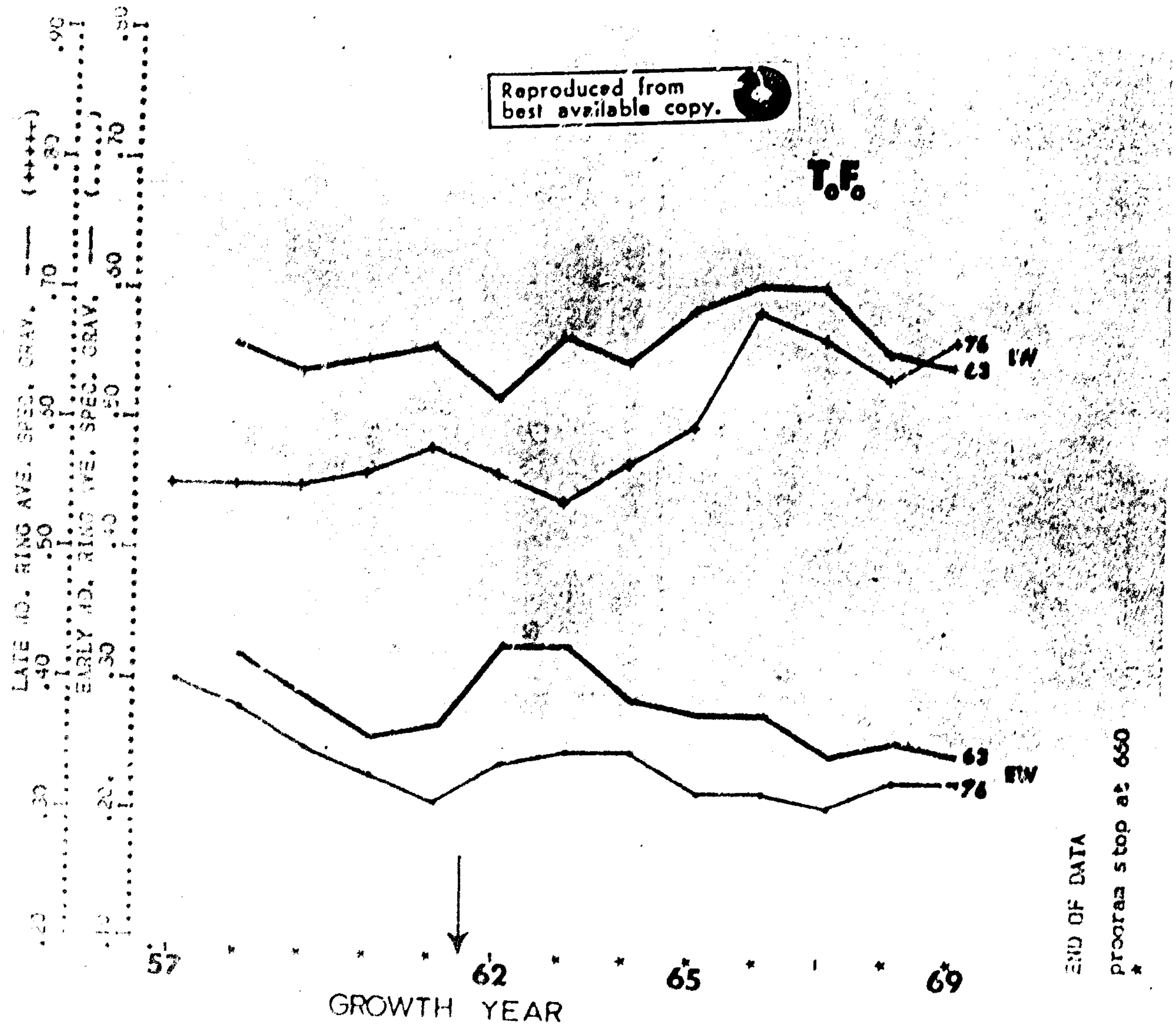


Figure 16.--A comparison of the average earlywood and latewood specific gravities for the same two trees described in figure 14. Both fractions are consistently higher in density for tree 63.

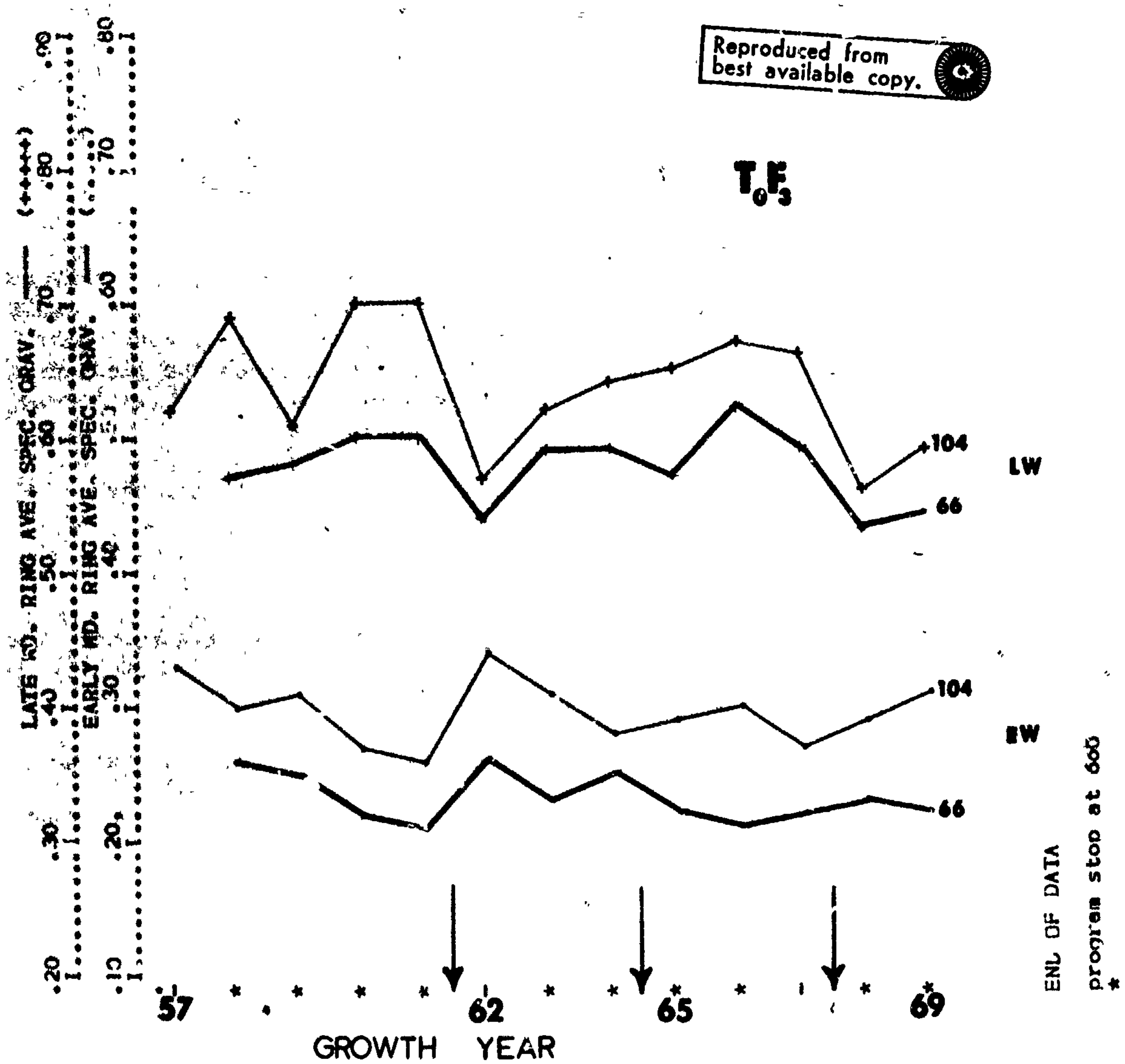


Figure 17.--A comparison of the average earlywood and latewood specific gravities for the same two trees described in figure 15. Both fractions are consistently higher in density for tree 104.

These examples clearly indicate the advantage of starting with genetic stock selected for high juvenile wood specific gravity, in addition to high volume growth potential. Moreover, the data indicate that the density ranking of a tree relative to its peers remains the same after fertilization or thinning as before. Thus, if stock is selected for potentially high density juvenile wood, the anticipated gains in density should persist and still be realized even if growth is accelerated by subsequent silvicultural treatments.

Summary and Conclusions

Many more interesting points could be discussed concerning these data, but only the most conclusive have been presented. It must be remembered that this study resulted from a sampling of only a few trees, and that these trees represent a particular age bracket growing on a particular site; thus, the extent to which the findings can be generalized to other situations remains to be determined. This particular situation, nevertheless, clearly supports the following conclusions:

1. Fertilization, and to a lesser extent thinning, definitely affected the within-ring, individual fiber densities. More intermediate-density type fiber resulted because of lowered latewood density and increased earlywood density. This type of change should contribute favorably to pulp characteristics.

2. Overall ring specific gravity was not significantly changed by treatment. The principal effect noted was an indicated prolongation of the low average density typical of the juvenile growth period.

3. The selection of genetic stock superior in juvenile wood density is just as important for maximizing return from cultured stands as it is for uncultured stands. Trees genetically superior in density appear to maintain their superiority irrespective of subsequent fertilization or thinning.

4. X-ray analysis of increment cores, enabling simultaneous assessment of both fiber quantity and fiber characteristics, is a highly useful method for obtaining tree growth information.

* * *

Lawrence, Champion Papers--Did I gather from your presentation that your thinned and fertilized trees show more variation than normality, that is, more of the higher density within the ring? I got the impression from the previous discussion that the reverse was true--that in the case of fertilization fibers tended to be more uniform and less extreme, less high density and less percentage or less proportion in the high-density and low-density range. Am I mixed up on that?

Megraw--That's exactly the impression I got, too. Of course, this is a different species and entirely different growing conditions. There was one fertilizer treatment there and perhaps the rate of application was not so heavy that it would overshadow the release effects. The trees that were fertilized showed a slight decrease in the amount of the higher density wood and a very slight increase in amount of low-density wood. But not enough to be statistically significant with the small number of trees that we had. The impression that I got from my data was that, with sufficient fertilization, probably the medium range would be reduced quite a bit.

Larson, Forest Service--As I understand the experiments you conducted, Bob, this thinning and fertilization treatment was superimposed in a middle-aged or existing stand, is that correct?

Megraw--Right. Forty-nine years old; it was roughly 36 to 39 years old when the wood was put on.

Larson--In so doing you actually more or less interrupted or modified the normal growth trend. Now if these fertilization and thinning studies had been conducted at an earlier age, in which the growth trends were more normal rather than going on the downhill side, do you think that this uniformity might not have been consistent throughout the life of the tree rather than getting this abrupt change?

Megraw--This is something that you can take heart in because I rather suspect it might be different if we started at a younger age.

Kellogg, Canadian FPL--I'd like to ask about the level of moisture content.

Megraw--About 12%. The reason I selected 12% is because it is a fairly universal moisture content for testing and doesn't change much while you are making your tests.

Kellogg--How do you adjust for that? When you start taking these density values that you're measuring with the X-rays, and start blowing this up in terms of yield per acre and tons and such, you have to adjust for moisture content. How do you make that adjustment? Or would it make more sense to dry it down to an ovendry condition and make all your measurements in the ovendry state?

Nearn, Weyerhaeuser--Anyone who has ever tried drying anything down to the ovendry state and doing anything with it realizes why that is not a good approach. You just can't keep it at an ovendry basis. Generally people doing this kind of work do so at a moisture content that's convenient and stays constant for them. In our

case we happened to have a 50-70 room. Moisture content is a matter of arithmetic and can be accounted for. If you wish to make actual weight projections on a volume or a per acre basis, the main thing is that you're consistent with what you're trying to do. It you're trying to get absolute numbers, take the moisture content you're working at and convert it mathematically to bone-dry data; then express everything in terms of bone-dry data. I don't think the conclusions you draw will be radically affected by the particular moisture content that you operate at if you are reasonable and consistent.

PATTERNS OF WOOD DENSITY DISTRIBUTION

AND GROWTH RATE IN PONDEROSA PINE

by

R. M. ECHOLS[1]

Abstract

Wood density distribution within and across annual rings was measured by X-raying increment cores from two growth periods in unthinned, thinned, and thinned and fertilized ponderosa pine trees. The unthinned trees decreased in growth rate and increased in wood density. Thinning increased growth rate 33.3%. Trees released but not fertilized increased in average ring width from 3.70 millimeters to 4.85 millimeters, but decreased slightly in wood density; fertilized trees increased in ring width from 3.85 millimeters to 5.15 millimeters and increased in wood density. A characteristic pattern of wood density distribution, resembling a chi-square curve, was found in all trees, with variations occurring most frequently at the highest and lowest density levels. Wood uniformity appeared to be controlled by the relative amounts of very high- and low-density wood, with high densities exercising the greatest influence. Analysis of density distribution may prove useful for characterizing wood for utilization purposes.

Introduction

Research on tree development after thinning, fertilization, or other silvicultural treatments leaves little doubt that growth rate can usually be increased by release, and often enhanced by supplying additional nutrients. The gross effects on wood characteristics in trees have been reported for many species. We know that wood density may or may not decrease as growth rate increases, but many questions need to be answered in greater depth. When gross change is slight, is there a redistribution of density toward high and low levels that achieves the same balance? When density increases or decreases, is it general across the spectrum of low to high density in growth rings? Or is the modification more differential and specific for certain levels of density?

This paper reports a study of wood in 46-year-old Sierra Nevada ponderosa pine that was thinned in 1961 and fertilized in 1962. Changes in growth rate, wood density, and wood uniformity (or density distribution) were found in comparing the thinned trees with unthinned controls.

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Materials and Methods

In 1961, a stand of young ponderosa pine trees on the Stanislaus National Forest, in central California, was thinned for conversion to a seed production area. The level 15-acre site lies at 4,000-foot elevation on a deep Cohasset loam soil. Crop trees were left 30 to 40 feet apart, and competing vegetation was removed (fig. 1). A cooperative study with the University of California was begun in 1962 to learn the effects of supplemental fertilizers on flowering and cone production (Krugman, 1965). Six groups of seven trees, similar in crown and bole diameters, were selected for fertilization. In each group the trees were treated as follows:

Tree	Treatment
1	None (Check)
2	N
3	N, S
4	N, S, K
5	N, S, K, P
6	N, S, K, P, Bo
7	N, S, K, P, Bo, Zn

Fertilizer was applied only once.

By summer 1971, some growth differential was already noticeable. The difference was readily apparent when diameters of the treated trees were compared with those in an adjacent unthinned stand of similar age and type. The six thinned but unfertilized trees averaged 18.3 inches DBH; the 36 thinned and fertilized trees, 18.5 inches DBH; and six randomly selected untreated trees, 14.1 inches DBH.

I extracted large (12-mm. diameter) increment cores from bark to pith at breast height in all 48 trees for detailed wood analysis.

The cores were conditioned by drying to about 8% M.C. and returning them to 12% M.C. in a conditioning cabinet. All cores were measured at 12% M.C. Entire cores were X-rayed by using the moving-slit method of traversing the samples to avoid parallax distortions. Although the principle was reported earlier (Echols, 1970), I designed new equipment which reduced vibrations and removed previous limitations on sample size (fig. 2). The X-ray tube head is mounted in a cradle that moves along heavy rails at a constant speed inside a lead-shielded cabinet. The increment core and an X-ray filmstrip are placed on an adjustable platform, which is positioned immediately below the path of the moving head. As the X-rays pass through a 2-millimeter slit in 1/2-inch lead shielding, they are confined to a virtually parallel plane that produces clear images on negatives (fig. 3).

Two growth periods were marked on the X-ray negatives, representing the 9 years before thinning (1953-61) and after thinning (1962-70). The negatives were analyzed with a densitometer that produced chart tracings representing wood density variations. The density distribution was measured with an integrator that divided the range of density into 14 classes (0.20 to above 0.85) and recorded the amounts of wood in each 0.05 class. A uniformity number for each wood sample was derived from the relative distribution of wood in the 14 density classes by using the mean density as a base.

Fig. 1. Manuel Mill site: A, not thinned; B, thinned and cleared of low vegetation.

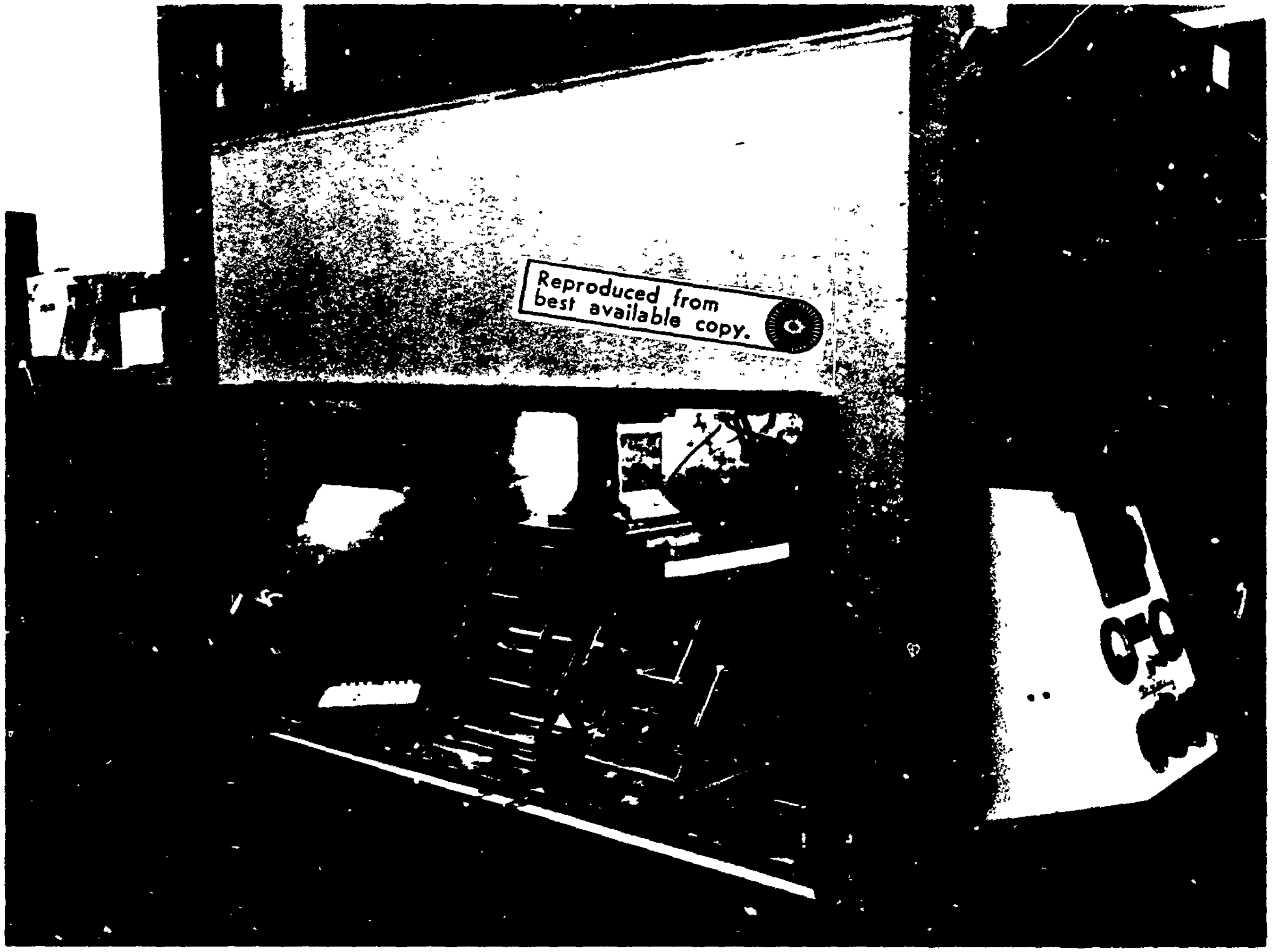

Fig. 2. X-ray cabinet and controls for moving-slit exposures.

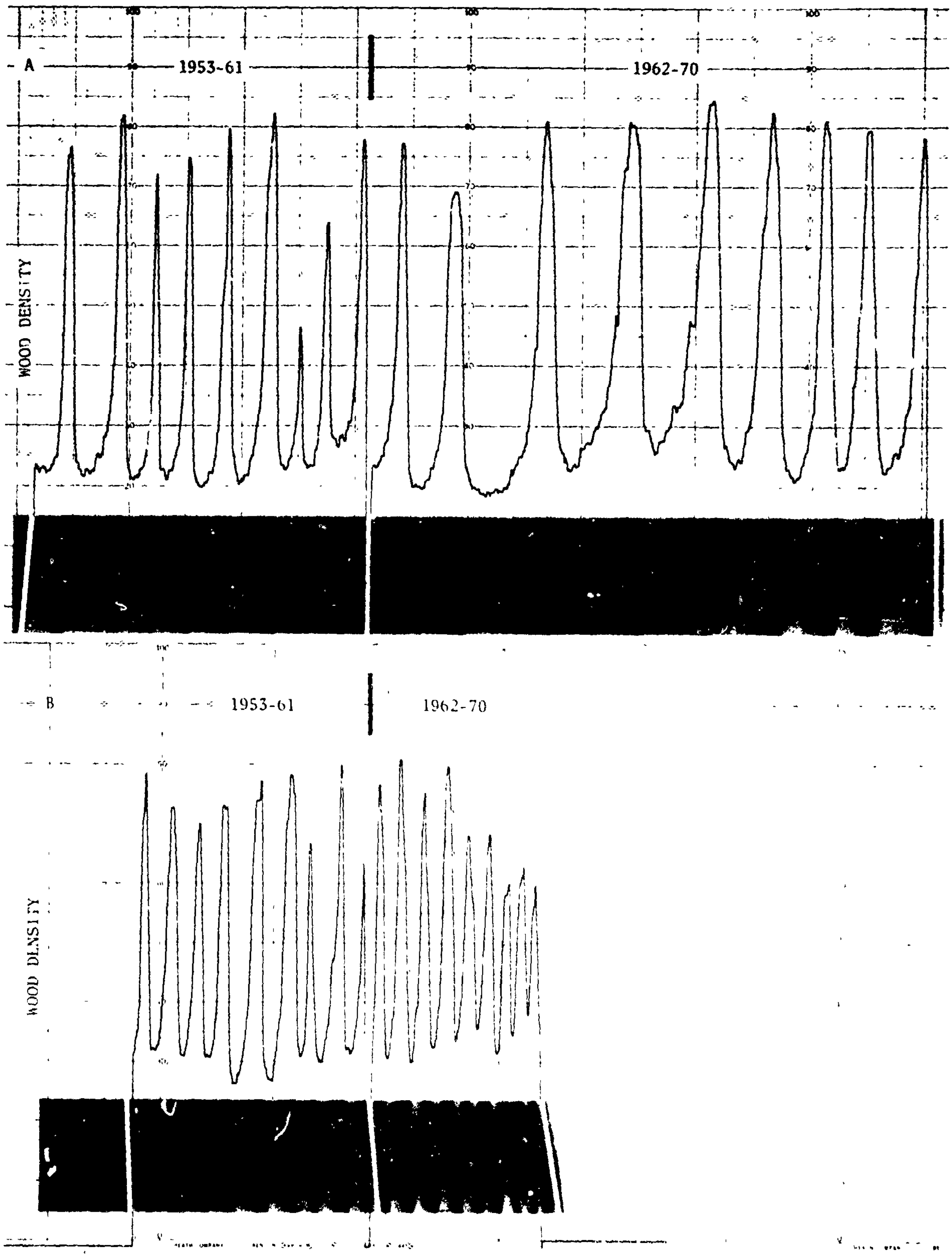

Figure 3.--X-ray prints and densitometer chart tracings of wood density variations for two 9-year periods in 46-year-old ponderosa pine: Upper, trees thinned in 1961 and fertilized in 1962; lower, trees unthinned and not fertilized.

In addition to the 9-year total measurements, individual rings were analyzed in three trees (unthinned, thinned, and thinned and fertilized) to obtain density distributions and changes within the two 9-year periods. The rings formed in 1953, 1957, and 1961 (before thinning), and in 1962, 1966, and 1970 (after thinning) were compared. Other measurements included ring widths and total segment lengths.

Results

Table 1 summarizes the relationships of the treatments to growth, wood density, and wood uniformity.

Growth

All of the released trees responded to thinning with accelerated diameter growth. Growth rate jumped by 33.3% during the period 1962-70, compared with the previous 9 years. Fertilization had only slight effect on growth rate, being largely masked by the release effects of thinning. In the thinned trees, average ring width increased from 3.70 millimeters to 4.85 millimeters after 9 years; in the thinned and fertilized trees, it increased from 3.85 millimeters to 5.15 millimeters. These differences were significant, but differences in fertilizer combinations were not. The six unthinned and unfertilized trees showed a decrease in ring width for the two periods, averaging 2.59 millimeters for 1953-61 and 1.69 millimeters during 1962-70 (fig. 4). A third-year response to release was evident in the thinned trees, and was more pronounced in the trees that also received fertilizers. Because the six fertilizer combinations yielded similar results and could not be distinguished individually, they were pooled for data analysis. Any fertilizer response noted can therefore be related to nitrogen, the common ingredient.

Wood Density

Wood densities in the 1953-61 growth rings were not significantly different from the 1962-70 rings in the thinned trees, whether fertilized or not. The unfertilized trees showed a 4.4% decrease in wood density for the second period, dropping from 0.366 to 0.350. At the same time the fertilized trees increased 2.9% from 0.342 to 0.352.

By comparison, trees not thinned increased in wood density from 0.350 for the 1953-61 period to 0.414 for the 1962-70 period. This difference reflects the normal pattern of wood density increase in subsequent years of growth in ponderosa pine. Such density increase is commonly associated with decreasing ring width.

Density Distribution

A characteristic pattern of wood density variation was found in all trees. The curves resembled a chi-square distribution (fig. 5). The departures that occurred were the most pronounced at the ends of the density scale. Because the percent of wood was

Table 1. Growth, wood density, and wood uniformity in 46-year-old ponderosa pine trees for the periods before and after treatments.

Treatment	DBH		Ring Width		Wood Density		Wood Uniformity 1/	
	1961	1971	1953-61	1962-70	1953-61	1962-70	1953-61	1962-70
	In.	In.	Mm.	Mm.				
None	12.9	14.1	2.59	1.69 *	0.350	0.414	248	227
Thinned only	14.7	18.3	3.70	4.85 **	0.366	0.350	284	318 **
Thinned and fertilized	14.4	18.5	3.85	5.15**	0.342	0.352	282	308 **

1/ Smaller the number, greater the uniformity.

* Statistically significant at 5% level.

** Statistically significant at 1% level.

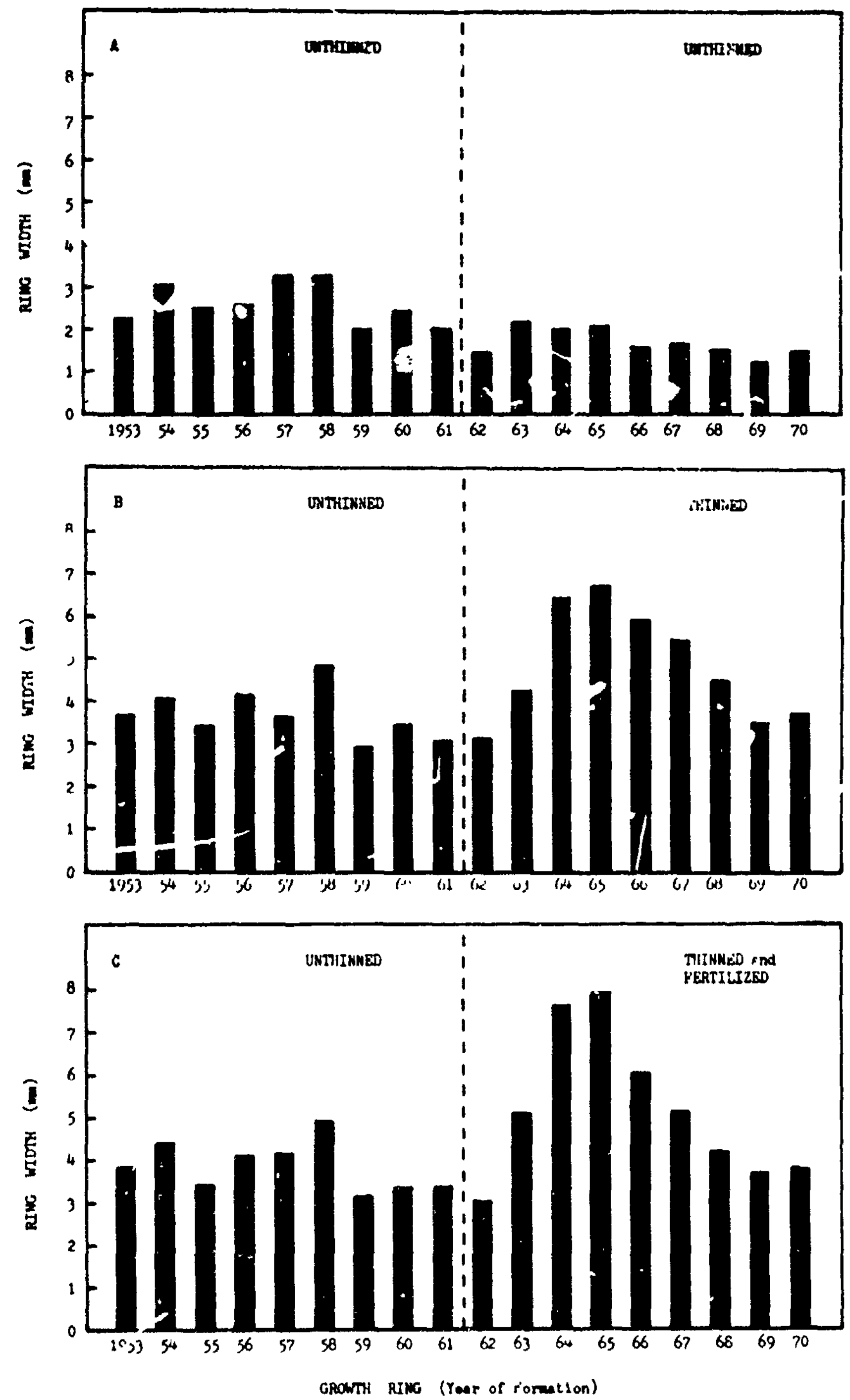

Fig. 4. Ring widths in ponderosa pine for two 9-year periods: A, trees not thinned; B, trees released by thinning; C, trees released and fertilized.

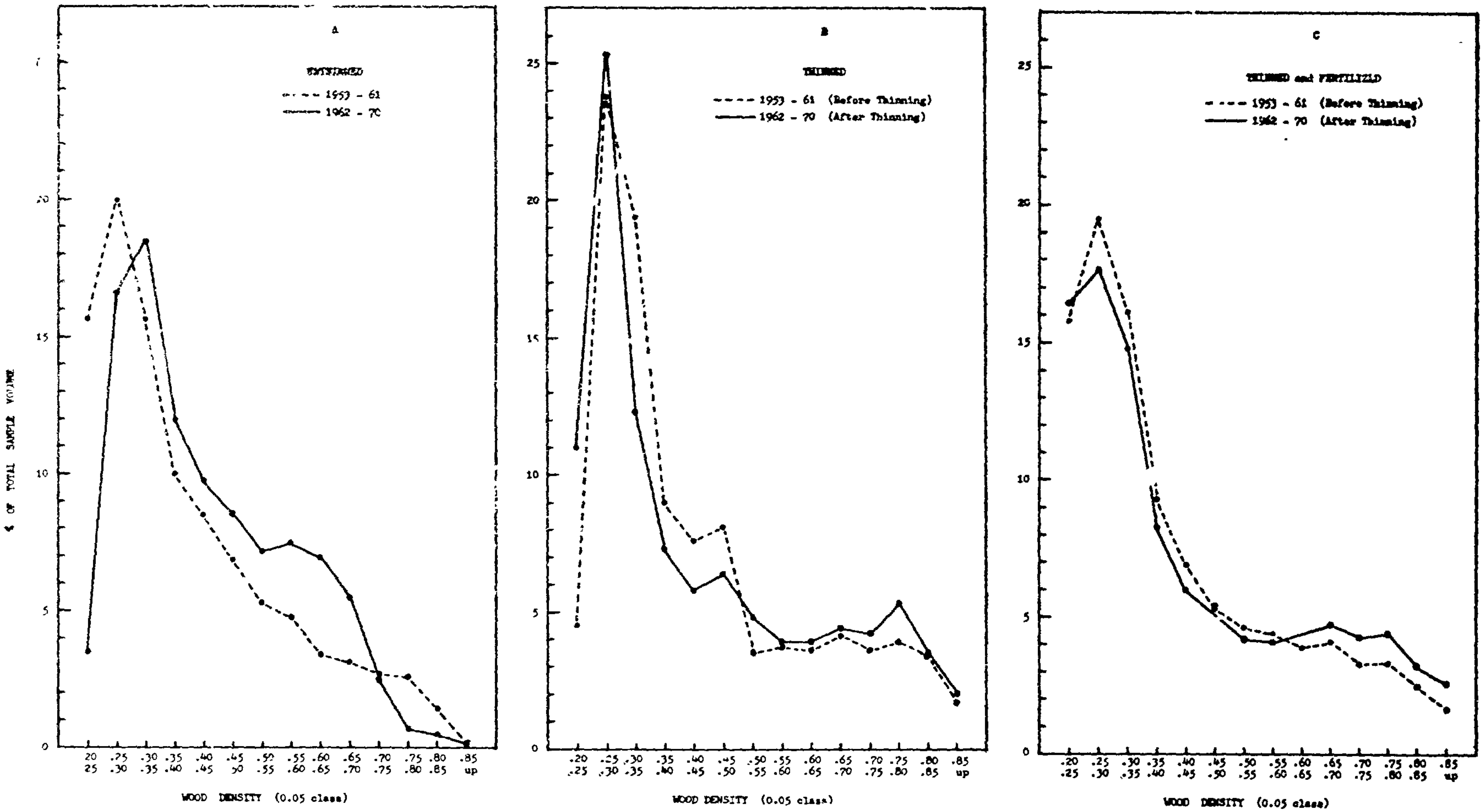

Fig. 5. Wood density distribution in ponderosa pine expressed as percent of sample volume in each of 14 density classes: A, trees not thinned; B, trees released by thinning; C, trees released and fertilized.

computed for each of the 14 density classes, the relative distribution data was not affected by the length of each increment core. Figure 6 shows the density distributions expressed in absolute amounts of wood (percent of sample X core length). The thinned and unfertilized trees (fig. 6B) developed more wood in the density ranges of 0.20 to 0.30 and 0.50 to 0.85 after thinning than in the period before release. The greater amounts of wood in the low density range resulted in the slight decrease in mean sample density noted earlier--from 0.366 to 0.350; but the basic pattern was not changed.

When growth from 1953-61 was compared with that from 1962-70 in the fertilized trees, a remarkably consistent increase in amounts of wood was found in all density classes (fig. 6C). This increase resulted in the change in mean density from 0.342 to 0.352, but again the basic pattern was unchanged.

Trees which were not thinned increased in mean density during the 1962-70 period, but diameter growth decreased (fig. 6A). A lower volume of wood was formed in the 0.20 to 0.55 and 0.70 to 0.80 density ranges, but the increase in mean density primarily reflected the much smaller amount of wood formed in the 0.20 to 0.35 range.

Wood density distributions in the three trees selected for individual ring analyses showed no change in the general pattern resembling the chi-square curve (fig. 7). In the unfertilized tree which had unchanged mean wood density for the period after release, the increased amounts of low-density earlywood in the second period were counterbalanced by additional wood of higher density formed toward the end of the growing season. This in turn reduced uniformity.

Wood Uniformity

One method of expressing wood density distribution in a sample is by means of a single uniformity number (table 2). Taking the mean density as a base, the percent of wood in each 0.05 density class above and below the mean are multiplied by weighting factors 1, 2, 3, . . . n, then added to the percent of wood in the class containing the mean. The result is a combined number derived from the relative distribution of wood in all of the density classes. Number 100 indicates uniform, virtually homogeneous wood, and is the lowest number that can be derived. Higher numbers represent less uniform wood. These uniformity numbers can be used to compare wood samples and could be extended to represent trees and stands with suitable correlations.

The decrease in wood uniformity in the thinned trees during the 9 years after release was statistically highly significant (table 1). It averaged 15.1%. This decline was true for both fertilized and unfertilized trees. By contrast, the unthinned trees gained 14.9% in uniformity. The more uniform wood in the slower-grown, untreated trees typifies that found in the narrower growth rings associated with trees under highly competitive conditions. This wood is also similar to old-growth wood in large trees.

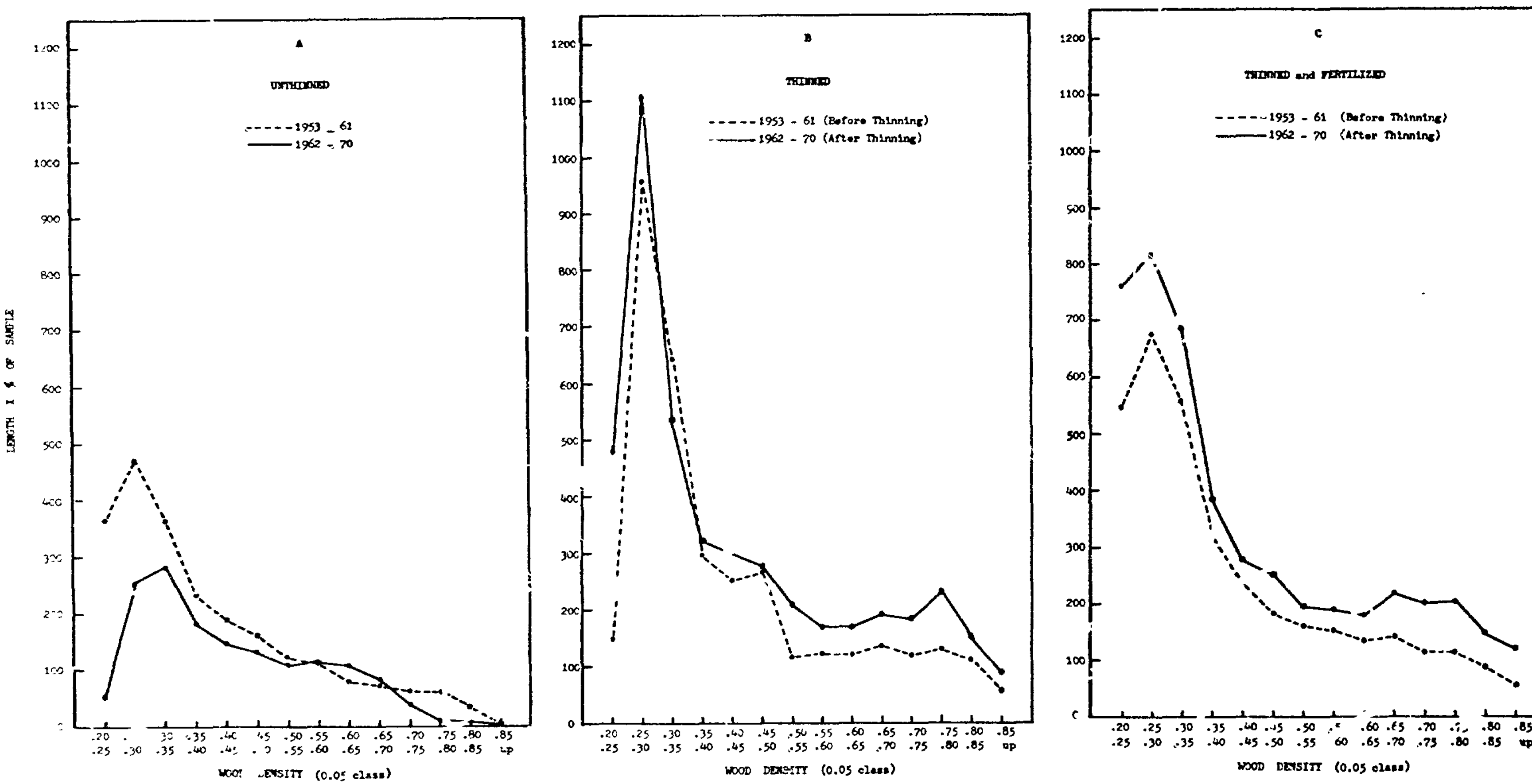

Fig. 6. Index of total amount of wood in each density class in ponderosa pine based on increment core length X percent of sample: A, trees not thinned; B, trees released by thinning; C, trees released and fertilized.

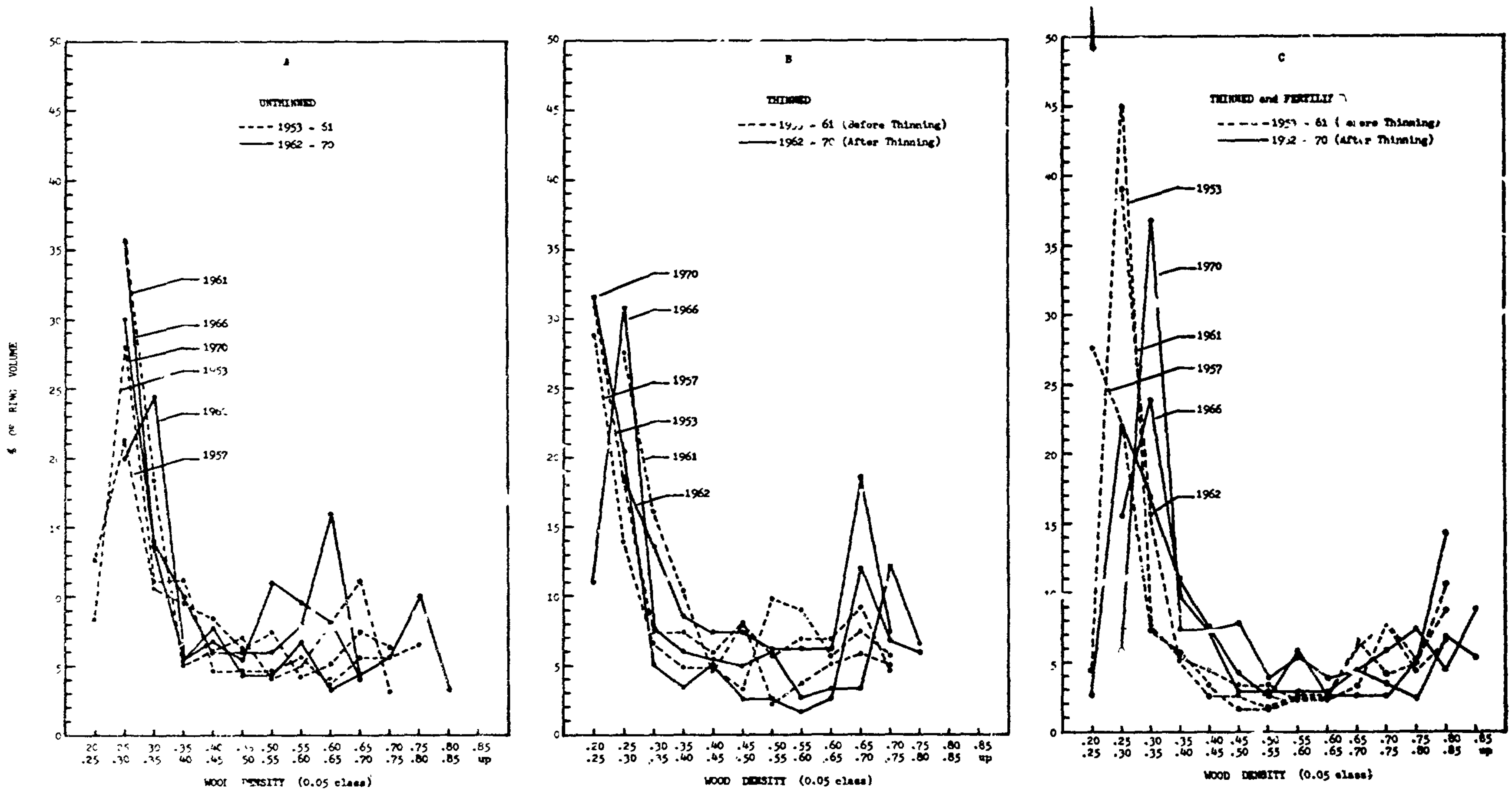

Fig. 7. Wood density distribution in individual growth rings, expressed as percent of the ring in each of 14 density classes for the years 1953, 1957, 1961, 1962, 1966, and 1970: A, tree not released; B, tree released by thinning; C, tree released and fertilized.

Table 2. Example of uniformity computation based on scope and magnitude of departure from mean wood density in ponderosa pine. Mean density = 0.353

Density Level	.20-.25	.25-.30	.30-.35	.35-.40	.40-.45	.45-.50	.50-.55	.55-.60
Wood (pct.)	1.6	30.1	15.0	9.0	6.7	5.5	5.5	5.2
Multiplier	3	2	1	1	1	2	3	4
Uniformity Increments	4.8	60.1	15.0	9.0	6.7	11.0	16.5	20.8

Density Level	.60-.65	.65-.70	.70-.75	.75-.80	.80-.85	.85 .90	
Wood (pct.)	4.9	5.6	5.2	3.5	1.6	0.6	Uniformity number: 287
Multiplier	5	6	7	8	9	10	
Uniformity Increments	24.5	33.6	36.4	28.0	14.4	6.0	

Discussion

Ponderosa pine is a relatively low-density species, averaging 0.30 to 0.40 when ovendry. By comparison, ovendry southern yellow pine averages 0.52 to 0.66; and Douglas-fir averages 0.45 to 0.51 (Panshin and de Zeeuw, 1964). Wood density within growth rings of ponderosa pine in this study ranged from about 0.20 to more than 0.85, but the larger amounts of the lower density wood reduced the mean. In the 48 trees measured, 50% of the wood was in the three lowest density classes, from 0.20 to 0.35, while the remaining 50% covered the 11 classes above 0.35 to more than 0.85. Beginning at about 0.35 a similar density distribution existed in all of the trees analyzed. The relative amount of wood ranged between about 5% to 12% of total volume and continued at the same amounts across the next four 0.05-density classes to about 0.55 (higher in some trees). Density variations occurred most frequently at the ends of the spectrum, rather than uniformly across individual rings. This occurrence can be explained in terms of the sequence of development of the secondary cell wall, or S_2 layer, in the tracheids.

At the beginning of each growing season, when cambial cell division starts, normal thin-walled tracheids are formed. The initial wall thickness is influenced by rate of cell division as well as by an inherent response to the water and nutrient supply, crown size, and general physiological efficiency of the tree. After the early period of growth, a balance is achieved in which reductions in cell division rate follow the increasing water stress conditions. This period coincides with the beginning of the horizontal portions of the density distribution curves, and in some species has been related to a cessation of shoot growth and an accumulation of inhibitors in the stem (Larson, 1960; Wodzicki, 1964; Kozlowski, 1971). As the inhibition of cell division begins before the movement of cell wall materials down the stem starts to taper off, the excess cellulose that is manufactured is deposited along with other products inside the most recently formed tracheids as increasingly thicker S_2 layers. Under the same conditions some trees can carry on this process longer than others, resulting in greater amounts of medium- to high-density wood in rings. Other trees slow their cambial divisions more quickly, resulting in even greater amounts of cellulose deposited in the outer tracheids and causing the higher densities that we have encountered. If this lag time were measured it might be found characteristic of a species as well as indicative of localized moisture stress conditions.

An examination of the density curves for individual rings showed no apparent carry-over of the supply of cell wall raw materials from one season to the next. A growth ring with higher or lower density latewood could not be associated with the amount of lower or higher density earlywood in the next ring. Each season appeared to be a separate event. Thinning and fertilization did not decrease wood density in this study, but the normal trend of systematic increase was halted. Most of the variations in density distribution that occurred were in the low- and high-density classes. Therefore, if we want to achieve greater uniformity in wood, we should concentrate on reducing the relative amounts of extremely thin- and thick-walled tracheids formed at the beginning and end of the growing seasons. Rather than the chi-square type of curve (figs. 5 and 6), a uniform wood would produce a normal curve--high in the middle and tapering abruptly at the ends.

Analysis of density distribution in growth rings of trees can provide us an additional basis for characterizing wood from a utilization standpoint. More information is needed on the relation of density distribution to pulp processes and papermaking, to strength of wood materials, to assigned stress ratings, and to seasoning and conversion processes. Density distribution, or wood uniformity, when considered along with mean density, could become an index to suitability of wood for its various uses, within the ranges of species and sizes available in the future.

Summary

The distribution of wood density within and across growth rings was analyzed in 48 ponderosa pine trees from a seed production area on the Sierra Nevada in central California. Forty-two of the trees had been released by thinning in 1961, and 38 were given additional fertilizer treatments. Large increment cores were extracted, conditioned to 12% M.C., and X-rayed to measure growth and wood density distribution for the 9-year periods before and after thinning and fertilization. During the second period the growth rate of the released trees increased by 33.3%, with average ring width increasing from 3.83 to 5.10 millimeters. Fertilization had some effect on growth, but there were no differences in various fertilizer combinations. The unthinned trees decreased in growth rate and increased in wood density. Thinned and unfertilized trees decreased in wood density from 0.366 to 0.350, but the fertilized trees increased from 0.342 to 0.352.

A characteristic pattern of wood density was found in all trees, resembling a chi-square distribution. Variations occurred most frequently in the lower and upper density levels, rather than uniformly throughout growth rings. An increase in mean density was the result of a greater percent of higher density wood (above 0.55), while lower mean density was associated with a higher percent of wood in the 0.20 to 0.35 range. Wood uniformity appeared to be controlled by the amounts of wood at the very high- and low-density levels, with high densities exercising the greatest influence.

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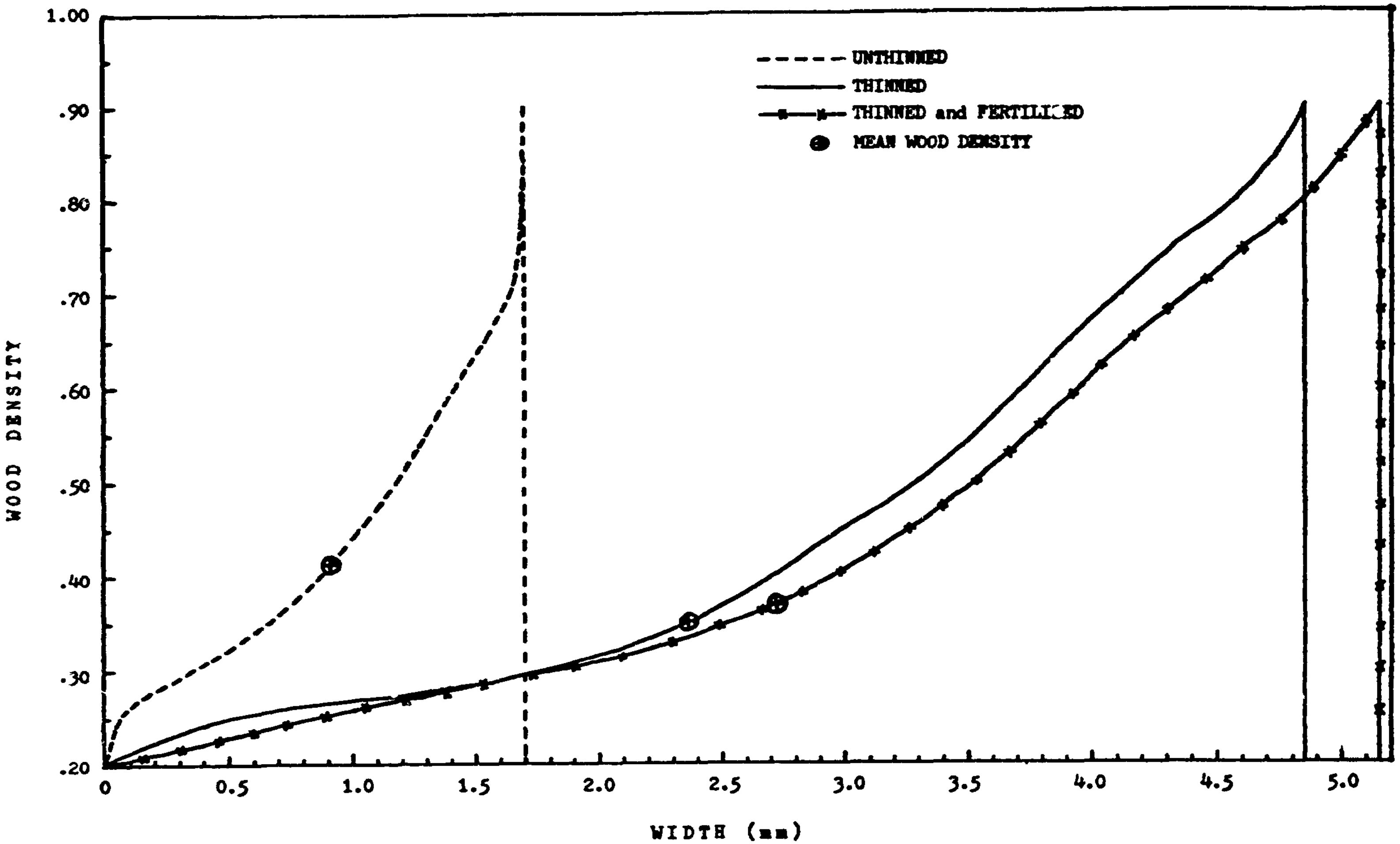
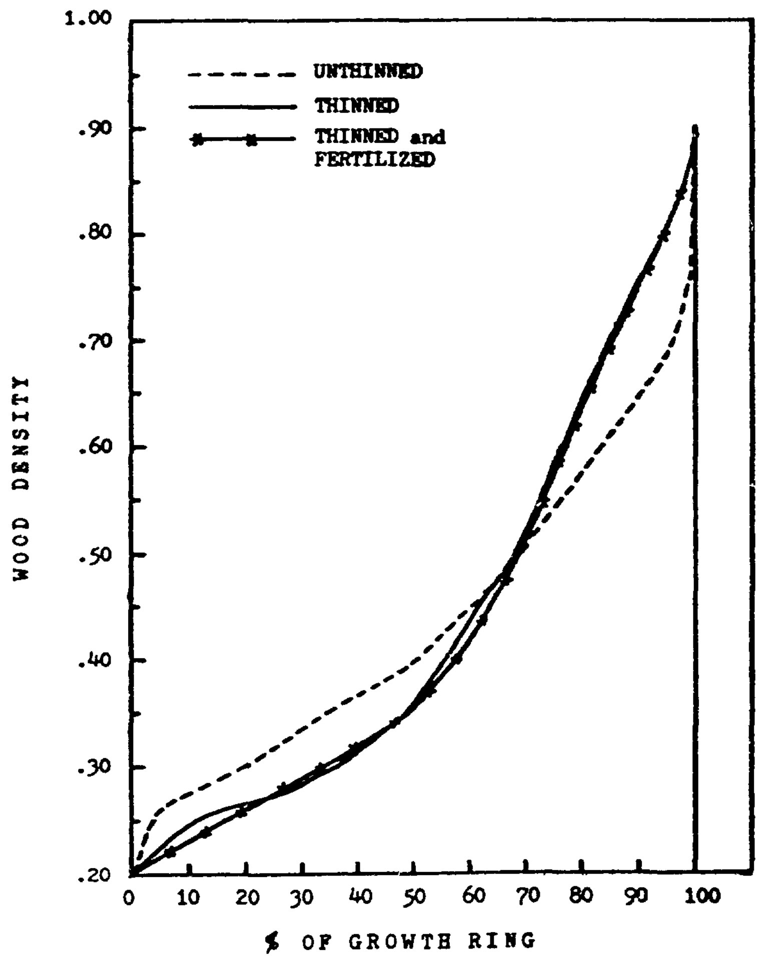


SYNTHETIC, COMPOSITE GROWTH RINGS -- 46-YEAR-OLD PONDEROSA PINE

MEAN WOOD DENSITY DISTRIBUTION, 1962 - 1970 (Each ring represents mean of all rings in all trees in one treatment)

Based on: Echols, R. M. Patterns of Wood Density Distribution and Growth Rate in Ponderosa Pine. Paper presented to FPL/API-TAPPI Symposium, Madison, Wis., Nov. 10, 1971.



WOOD DENSITY DISTRIBUTION -- 46-YEAR-OLD PONDEROSA PINE

SYNTHETIC, COMPOSITE GROWTH RINGS

(Each ring represents mean of all rings in all trees in one treatment for period 1962-70)

	Ring Width	Mean Density	Uniformity
UNTHINNED	1.69 mm	.414	227
THINNED	4.85	.350	318
THINNED and FERTILIZED	5.15	.352	308

Based on: Echols, R. M. Patterns of Wood Density Distribution and Growth Rate in Ponderosa Pine. Paper presented to FPL/API-TAPPI Symposium, Madison, Wis., Nov. 10, 1971.

INFLUENCE OF IRRIGATION AND FERTILIZATION ON GROWTH AND WOOD PROPERTIES OF QUAKING ASPEN

by

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MILES K. BENSON

MARIANNE L. HARDER

Abstract

Fertilizer and irrigation treatments were applied to a 6-year-old quaking aspen (Populus tremuloides Michx.) sucker stand growing in northern Wisconsin. Three years after the start of the treatments, growth response and wood quality changes were evaluated. Volume growth was approximately 140% greater for the "fertilizer plus water" treatment than on the control plots. Specific gravity appeared to be only moderately reduced as a result of the increased rate of growth. The fiber lengths of the trees from the control plots were significantly shorter than the average fiber length of the trees receiving water only. Fiber length was positively correlated to total height. Vessel-to-fiber ratios were not influenced by the treatments or related to specific gravity, height, or diameter growth.

Introduction

Ever-increasing pressures by environmentalists to restrict how and where wood products can be harvested, along with mounting top management pressure to maximize total production and make the best economic use of the shrinking land resource available for forest production, has resulted in the development of new and exciting forest harvesting and forest management concepts. Terms like "silage sycamore," "pucker brush," "chipping in the woods," "mini-rotation," and "chipping at the stump" all imply the future use of short rotations, juvenile wood, and improved utilization. There is also evidence that much of the wood produced by the above intensive management systems will be from trees that are more rapid growing than normal. This, in turn, raises the question of the influence of accelerated growth on wood quality and, in the case of pulpwood, how this will influence pulp quality.

Lake States aspen or "popple," which includes quaking aspen (Populus tremuloides) and bigtooth aspen (Populus grandidentata), has for the past 8 to 10 years amounted

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to approximately one-half the total pulpwood harvest in the Lake States region. Rapid growth, prolific suckering ability, and the ability to grow on a wide variety of upland sites makes aspen a prime prospect for use in intensive management systems in the Lake States region (Einspahr and Benson, 1970).

Previous studies within the genus Populus on the influence of rapid growth on wood quality have mainly involved the black poplars, section Aigeiros, within the genus Populus. Only a limited amount of information regarding the effect of acclerated growth on wood quality is presently available for the aspen (section Leuce). Kennedy (1968), in reviewing the anatomy and fundamental wood properties of poplars, discussed in some detail the influence of rate of growth on such wood properties as fiber length, specific gravity, and chemical content. In view of Kennedy's comprehensive review only a brief summary of previous findings has been included.

The influence of growth rate on specific gravity of poplars has been controversial and of considerable concern. A number of researchers, working primarily with the black poplars (Kennedy, 1968), found that there was a negative correlation between growth rate and specific gravity In contrast, the work of Boyce and Kaeiser (1964), Walters and Bruckmann (1965), and Farmer and Wilcox (1966), in studies with cottonwood failed to find any relationship between growth rate and wood density. Kennedy concludes that rapid growth rate appears to depress specific gravity and that the conflicting results appear to have resulted from studies in which growth rate varied only moderately or studies in which confounding genetic influences apparently were involved. The work of van Buijtenen et al. (1959), Brown and Valentine (1963), Einspahr and Benson (1967), and Pronin and Lassen (1970) with quaking aspen suggests that the specific gravity of aspen may be less strongly influenced by growth rate than appears to be the case for black poplars. Here again, less variation in growth rate and genetic factors may be the reasons for the reduced influence.

Fiber length-growth rate relationships have been less widely studied and appear to be less controversial than the specific gravity-growth rate relationships. Most researchers working with Populus species have concluded that fast growth rate was significantly related to longer fibers (see review by Kennedy, 1968). In the present study the authors have attempted to evaluate the influence of fertilization and irrigation treatments on growth rate, fiber length, specific gravity, and the vessel-to-fiber ratio of a 6-year-old quaking aspen sucker stand.

Methods and Materials

Experimental Trial

The wood samples used in this investigation were obtained from a fertilization and irrigation study being conducted on a 6-year-old quaking aspen sucker stand. The stand is growing on a sandy loam bench (rocky subsoil) about 30 feet above the Wisconsin River near Tomahawk, Wis. The trial was established to demonstrate the biological potential of young aspen sucker stands and is a part of a larger intensive forestry program at The Institute of Paper Chemistry.

The treatments were arranged in a three-replicate, randomized block design and the treatments included control, fertilizer (1,000 lb. per acre of $N_{20}P_5K_{10}Ca_{10}Mg_2$), irrigation (5 to 7 in. of additional moisture per acre as the season required) and fertilizer plus irrigation. The fertilizer was applied as a single application while the irrigation water was applied through an overhead sprinkler system using water pumped from the Wisconsin River. The treated plots (replications) were 150 by 200 feet. Permanent subplots (1/50 acre) were established within each replication and were used to monitor volume growth response. The 6-year-old sucker stand, when measured the fall before the study started, averaged 11.9 feet in height, 0.77 inch in diameter at breast height (DBH) and contained approximately 5,735 stems per acre over 0.5 inch in DBH.

Fertilizer and irrigation treatments were initiated in the spring of 1969. The wood samples employed in this study were from 9-year-old trees harvested in late August of 1971, three growing seasons after the start of the treatments.

Wood Samples

The wood samples used in the study were obtained by harvesting three representative size (dominant or codominant) trees from each of the three replications of a particular treatment. Since there were four treatments and three replications per treatment, the study being reported is based upon a total of 36 trees. The measurements reported are from disks taken at breast height and the measurements were further confined to wood from the three annual rings that were formed since the treatments were applied. Wood samples used were free from decay and reaction wood. Measurement data include disk diameter, total radial growth since treatment, specific gravity, fiber length, and the vessel-to-fiber ratio.

Measurement Techniques

Specific gravity information is based upon duplicate determinations made using two disks taken at breast height. The specific gravity values were obtained by dividing the dry weight by a weight of water equivalent to the green volume. Fiber measurements were obtained by macerating wedge-shaped samples containing the three annual rings of interest using the method of Spearin and Isenberg (1947). A minimum of 500 fibers were measured per tree including all intact, cut, and broken fibers 0.3 millimeter and longer. Measurements were made using an Institute-designed semiautomatic fiber-measuring device.

Vessel-to-fiber ratios were obtained using TAPPI Standard Method T401m-60 for quantitative determinations in recording the portion of the two types of elements from slides of the macerated material. Duplicate determinations were made and each determination was based upon counts of approximately 350 wood elements. The values obtained were expressed in terms of percent vessels.

Statistical procedures employed involved running standard analysis of variance calculations (randomized block design) on the data and where statistically significant differences were obtained, Duncan's multiple-range test (1955) was used to determine the reasons for significant "F" values obtained.

Results

The results obtained are presented through the use of the following five tables. Table 1 provides an insight into the volume growth on the test area and the changes that resulted from the treatments that were employed. Table 2 summarizes the data on the size of the trees that were sampled and information on diameter growth differences for the trees used in the wood property comparisons.

Table 3 summarizes the specific gravity, fiber length, and vessel-to-fiber ratio data obtained along with the diameter growth values used in calculating the response information given in table 2. The values presented are average values based upon measurements made upon three trees located within each of the replications of a treatment.

Interrelations between growth rate and wood properties were examined by calculating all possible simple correlations between total height, diameter at breast height, diameter growth, specific gravity, fiber length, and vessel-to-fiber ratio using individual tree data. Table 4 summarizes the results of these calculations. Correlation coefficients in excess of 0.33 are significant at the 95% level of probability while values larger than 0.42 are significant at the 99% level of probability.

Analysis of variance calculations were run using individual tree values to evaluate the influence of the fertilization and irrigation treatments on diameter growth, specific gravity, fiber length, and vessel-to-fiber ratio. The "F" values for treatments are summarized in the last line of table 5. Duncan's multiple-range test (1955) was used to further examine treatment means when significant "F" values were obtained. Table 5 summarizes the treatment means and the results of analysis of variance and Duncan's multiple-range test calculations.

Discussion of Results

The volume growth data in table 1 are presented to illustrate the magnitude of growth response obtained by the fertilizer and irrigation treatments. Measurement data obtained but not presented in this paper suggest fertilizer response was due primarily to increased diameter growth while irrigation resulted in improved height growth. The "fertilizer plus irrigation" treatment resulted in increases of approximately 140% over that of the control. The response obtained from this treatment resulted from a combination of increased height growth, increased diameter growth, and growing conditions that favored the survival and growth of a greater number of stems per acre.

The wood quality data were obtained from samples of 36 trees that were as representative as possible of the trees growing under the several growing conditions involved. A second measure of growth response was obtained by comparing the diameter growth of the sample trees. This comparison was made by measuring the diameter increases that resulted since the treatments had been applied (last 3 annual rings). Analysis of variance calculations on diameter growth since treatment indicate there was a significant difference due to treatments. Duncan's

Table 1.--Volume growth response of a 6-year-old quaking aspen stand[1]

Treatment	Volume growth change 1968 to 1970	1970 to 1971	Total	Response as percent of control
	Cu. ft. per acre	Cu. ft. per acre	Cu. ft. per acre	
Control	72	57	129	100
Fertilizer	89	61	150	116
Water	117	93	210	163
Fertilizer plus water	164	151	315	244

[1]Volume measurements were based upon 3 replications of each treatment and 4 1/50-acre subplots within each replication.

Table 2.--Dimensions and diameter growth of sample trees

Treatment	Average total height	Average DBH[1]	Diameter growth, last 3 annual rings	Diameter growth as percent of control
	Ft.	In.	In.	
Control	15.4	1.31	0.39	100
Fertilizer	15.5	1.42	.44	113
Water	19.7	1.45	.44	113
Fertilizer and water	18.2	1 60	.61	156

[1]Diameter at breast height outside bark.

Table 3.--Summary of diameter growth and wood property data

Treatment and replication	Breast height diameter growth since treatment	Specific gravity	Fiber length	Vessel-to-fiber ratio
	In.		Mm.	Pct.
Control				
A	0.42	0.335	0.643	7.9
B	.42	.335	.646	7.6
C	.34	.318	.693	7.5
Fertilizer				
A	.50	.350	.665	8.1
B	.38	.322	.696	6.0
C	.44	.329	.674	9.2
Water				
A	.46	.313	.714	7.7
B	.44	.340	.751	7.0
C	.42	.318	.679	8.6
Fertilizer plus water				
A	.58	.277	.681	7.1
B	.60	.293	.675	7.3
C	.64	.334	.696	6.6

Table 4.--Summary of correlation coefficients[1] between growth and wood properties

Variables	DBH	Total height	Diameter growth	Specific gravity	Fiber length	Vessel-to-fiber ratio
DBH	1.00	0.50	0.86	-0.47	0.25	-0.12
Total height		1.00	.36	-.23	.53	-.12
Diameter growth			1.00	-.35	.12	-.09
Specific gravity				1.00	.09	-.02
Fiber length					1.00	-.25
Vessel-to-fiber ratio						1.00

[1]Values greater than 0.33 are significant at the 95% level and values in excess of 0.42 are significant at the 99% level of probability.

Table 5.--Analysis of variance and multiple-range test calculations[1]

Treatment	Average diameter growth	Specific gravity	Fiber length	Vessel-to-fiber ratio
	In.		Mm.	Pct.
Control	0.39^x	0.329^x	0.661^x	7.7^x
Fertilizer	$.44^x$	$.334^x$	$.678^x$	7.8^x
Water	$.44^x$	$.324^x$	$.715^y$	7.7^x
Fertilizer plus water	$.61^y$	$.301^y$	$.684^x$	7.0^x
Analysis of variance "F" test for treatments[2]	37.00	4.12	4.87	.53

[1]Duncan's multiple-range test (95% level of probability), treatment means followed by a common letter are not significantly different.

[2]"F" test values greater than 2.90 indicate significant (95% level of probability) treatment influence.

multiple-range test made on the treatment means provides evidence that the "fertilizer plus water" treatment was significantly different from the control and the other two treatments. The diameter growth of the water and fertilizer treatments were very similar and were not significantly different from the diameter growth of the control trees.

When individual tree specific gravity values were used in analysis of variance calculations, the "F" test for treatments indicated that significant differences in specific gravity had developed as a result of the treatments. Multiple-range tests, when used to examine treatment means, provided evidence that the trees receiving the "fertilizer plus water" treatment had significantly lower specific gravity than the trees receiving the other treatments. By assigning the specific gravity of the control plot a value of 100%, the trees in the "fertilizer plus water" treatment turn out to have a specific gravity of approximately 92% of the control trees.

Vessel-to-fiber ratios, despite an apparent decrease in specific gravity due to the rapid growth, were not significantly influenced by the treatments applied to the experimental area. The methods used in determining the ratios were very reproducible and the results leave little doubt that no increase in proportion of vessels resulted from the applied treatments. These results do not speak, however, to the possibility of larger sized vessels or thinner walled fibers and vessels.

Fiber length of the sampled trees appears to have been significantly influenced by the treatments. The "water only" treatment had trees with the longest fiber length and interestingly enough the trees from this treatment were also the tallest of the trees sampled. Analysis of variance and Duncan's multiple-range calculations (table 5) demonstrated there were significant differences between treatments and that the significant "F" value obtained was due to fiber length differences between the control trees and the trees from the irrigated plots.

As a further check on the relationships that exist between growth rate and wood properties, all possible correlations were run between growth measurements and the wood property measurements. The correlations were run using the data from the 36 trees making up the study. These calculations are summarized in table 4 and revealed a highly significant (99% level of probability) correlation existed between fiber length and total height. Specific gravity was negatively correlated with both DBH and diameter growth but was not correlated with total height. Vessel-to-fiber ratios were not correlated with any of the growth parameters measured.

The results of this study, although not conclusive because of possible genetic confounding, indicate that fertilizer and irrigation treatments on aspen sucker stands that result in major increases in height and diameter growth can be expected to result in modest decreases in the specific gravity of the wood produced. Vessel-to-fiber ratios, it appears, will not be changed by major increases in growth rate while fiber length can be expected to increase a modest amount by environmental factors that improve the growth rate.

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* * *

Berklund, Nekoosa Edwards--Would you conclude that the fertilizer acted as a deterrent on fiber length from what you've said there?

Einspahr--No, I would say there's no significant difference to the fertilizer alone, as to what we could see there.

Berklund--When you had water and fertilizer, you had the longer fiber length.

Einspahr--No, the longest fiber length was water alone.

Berklund--But when you had fertilizer you had a shorter fiber. So I interpret that fertilizer acted as a deterrent to fiber length.

Einspahr--The fertilizer gave us the same fiber length as the control. I guess I was looking at it from the point of view that fertilizer did not decrease it in comparison to the control. But when you compare the fertilizer plus water treatment with the water, you did have a lower fiber length. This is correct. And it was significant.

Isebrands, Forest Service--Did you find reaction wood was quite prevalent in this material?

Einspahr--Really not. In this particular instance we restricted the samples we used for measurements and they did not have reaction wood. But we saw very little reaction wood. This might be different if you were looking at materials that were wider spaced and had more wind action and various things. At a high density like this the stand was pretty stable as far as any movement of tops and the things that might cause reaction wood.

Franklin, Forest Service--In terms of aspen culture, what are the minimum merchantability standings and what's going to happen to 5,700 trees per acre as you approach some sort of merchantable size class?

Einspahr--We think you can probably harvest these materials at 10 or 12 years of age and have reasonable hardwood quality. Several years ago, in cooperation with Owens-Illinois at Tomahawk, we harvested a stand that was between 17 and 18 years. This particular stand had 1,700 stems per acre, quite a high density for that age. We harvested this essentially by hand, but we got very high yield from this approach. We got in the neighborhood of twice the total volume of chips off the area as normally expected, so it appears we will be able to harvest these materials at fairly young ages. There are techniques for separating bark and wood if these are required by the end product, and there are some possibilities also of actually pulping the bark with the wood as in the sycamore. We've done this on some 10-year-old material with relatively little decrease in any strength properties and only slight drop in yield. I had hoped that I would have the micropulping data to go with this presentation today but I didn't have enough data to bring along.

Question--This young wood has very short fibers, less than I millimeter long. How useful are such fibers for industry? How does this length compare with the mature aspen fiber?

Einspahr--I have to explain two points. Measuring aspen fibers the way we do, we measure all fibers cut and broken, as well as the intact ones, so we run something like 10% or so below normal. We have used this method consistently through all our studies, all selected trees, all our pulping work. In the pulp this is all right, because this is the fiber that affects strength. So we are running something like 10% below someone else's aspen results. If you use our method of measuring fiber length, aspen in northern Wisconsin at the 30th annual ring runs about 0.95 fiber length. The best we have here at age 9 was 0.715. So this gives you a relative story on the fiber length of these young materials. Now some people have pulped aspen this young and had reasonable luck in using it. It runs in the same fiber length as maple, so it is suitable for certain types of material.

Maeglin, FPL--In measuring the fibers this way, do you include longitudinal parenchyma in these measurements?

Einspahr--No, we do not. It is strictly fibers. We limit the fibers, but cut fibers and broken fibers are included.

Bensend, Iowa State--As I recall in the literature, the length of fiber decreases as growth increases because the pseudotransverse cell division in the cambium to increase the cambial girth results in shorter cambial initials and eventually in shorter fibers. But the data that I've seen today does not really substantiate this.

Einspahr--Bob Kennedy, from Canada, reviewed the effect of specific gravity on *Populus* species, the effect of growth on specific gravity, and the effect of growth on fiber length. His conclusions for the black poplars, for instance, support this. They have longer fiber length with more rapid growth. So there are data to substantiate this fiber length-rate of growth thing. I think it's generally accepted that more rapid growth in the *Populus* species is associated with longer fiber length. True, most of the information is on relatively young trees. But that data seem to support the same trend we obtained.

Bensend--The explanation for the shorter tracheids in, say compression wood, is often given as the increased radial growth of compression wood. And the longer fibers in the latewood of conifers is explained on the basis of less pseudotransverse cell division in the cambium. But this apparently is not true in hardwoods?

Einspahr--I really can't speak for hardwoods in general. But in *Populus* this has been the case in the literature, particularly with the black poplars.

Larson, Forest Service--There is quite a bit of evidence to indicate that at least in juvenile wood there is a relationship between fiber length and internode elongation. And you did show a positive correlation between height growth and fiber length. And there are also studies in which gibberellic acid has been applied to aspen shoots to induce elongation of the internode. This increased fiber length. So we may have the two different interactions here--effect of elongation growth on fiber length of the young tree, and the effect of pseudotransverse divisions in an older tree as Dr. Bensend pointed out.

Einspahr--Certainly the evidence that I've seen in the literature has been primarily with younger trees. This might be the reason and the explanation of this difference here.

EFFECT OF NITROGEN FERTILIZER ON THE GROWTH RATE AND CERTAIN WOOD QUALITY CHARACTERISTICS OF SAWLOG SIZE RED OAK, YELLOW-POPLAR, AND WHITE ASH

by

HAROLD L. MITCHELL[1]

Abstract

In the mid-1930's experimental plots established in even-aged, pole-sized stands of mixed hardwoods were fertilized in the early spring with varying amounts of nitrogen. Leaf samples, for chemical analysis, were taken the fall of the same year that the fertilizer was applied, and increment cores, for radial growth measurements, were taken the year following fertilization. All species studied showed a significant growth response to nitrogen fertilization, and in all cases there was a strong correlation between soil nitrogen supply and the nitrogen content of the leaves.

Twenty-seven years later, sample trees of three species were cut on the control and the variously fertilized plots and bolts and cross sections therefrom were shipped to the Forest Products Laboratory for wood quality evaluations. This material was checked for specific gravity and toughness, and subjected to machining tests that included planing, turning, and shaping. The fast-grown wood produced by the fertilized trees was found to be just as suitable for the uses and products--mainly furniture, millwork, paneling--normally made from these valuable hardwood species as wood produced by the slower growing control trees. Also, so far as could be determined from this study, such wood would be just as good or better for pulp and paper products.

* * *

In the mid-1930's when I was assistant director in charge of research at the then privately owned Black Rock Forest in New York, I initiated what has since proved to be the first large-scale fertilizer experiments with natural forest stands in the United States. The results of some of these experiments, which have been under observation now for about 35 years, will be the subject of this paper. Emphasis will be on the quality of wood produced by certain hardwood species whose growth was greatly stimulated with nitrogen fertilizer.

By way of background, I should point out that the 3,100-acre Black Rock Forest, now known as the Harvard Black Rock Forest, is located in the Hudson Highlands

[1] Chief, Division of Wood Quality Research, Forest Products Laboratory, Forest Service, U.S. Department of Agriculture. The Laboratory is maintained in Madison, Wis., in cooperation with the University of Wisconsin.

of New York, on the west side of the river, between the U.S. Military Academy to the south and the village of Cornwall-on-the-Hudson on the north. The topography of the area is mountainous, with numerous rock outcrops. Elevations range from 450 feet to 1,461 feet. Little of the land was suitable for cultivation at the time of settlement in 1694, although there is evidence of considerable clearing for pasture. But mainly, the more rugged areas of the Highlands produced cordwood to make the charcoal required by the local iron industry, and later crossties for the railroads and fuel for the brick kilns that developed along the Hudson Valley.

During the 19th century, and perhaps earlier, the Highlands were clearcut on the average of every 40 years, and were frequently ravaged by wildfires. As a result, present stands are even-aged and mostly of sprout origin. The soils of the area--mostly stoney clay loam derived from glacial till--also show the effects of past abuse. They are generally low in organic material, low in nitrogen, and tend to be thin, especially at the higher elevations and on the steeper slopes. The soils of the area have been described in detail by Scholz (1931) and the geology by Denny (1938).

The objectives of the original experiments were: (1) To learn more about the nutritional needs of the local hardwood species so that we might improve our silviculture; and (2) to develop a foliar analysis technique that could be used as a management tool to estimate available nutrient levels of forest soils of unknown fertility with a relatively high degree of accuracy. At that point in time, when the country was just starting to recover from the Great Depression, no one seriously believed that the time would ever come when it would be economically feasible to use fertilizers to accelerate the growth of commercial forests.

In planning my research I most certainly did not anticipate the current surge of interest in what is known as high-yield forestry. In fact, I am frequently embarrassed by being credited with foresight I didn't possess. However, this fact in no way detracts from the value of the results of this pioneering research in today's more favorable climate.

In any event, starting in 1935 and extending over a period of 5 years, varying amounts of nitrogen, phosphorus, and potassium fertilizer, singly and in different combinations, were applied to about thirty 1/4-acre plots established in even-aged pole-size stands of mixed hardwoods on several different sites on the Black Rock Forest. Adequate unfertilized control areas were reserved for each series of variously fertilized plots established on a relatively uniform site. Fertilizer was applied, broadcast, to the undisturbed forest floor early in the spring. There was only one application. Leaf samples, for chemical analysis, were taken in the fall of the same year during that 2- to 3-week period when nutrient content is maximum and relatively constant (Mitchell, 1936). Increment cores, for radial growth determination, were normally taken the year following fertilization.

Starting in 1936, cooperation was developed with Dr. Robert F. Chandler, Jr., then assistant professor of forest soils at Cornell University. He had similar interests, and by duplicating some of the studies at the Arnot Experimental Forest, near Ithaca, it was possible to include several important species, such as beech and basswood, that were infrequent in the Hudson Highlands.

Since results with phosphorous and potassium applications were negative, so far as growth response was concerned, only the nitrogen data are considered here. All data from the 20 combined Black Rock and Arnot Forest nitrogen fertilized plots are presented in detail in Black Rock Forest Bulletin No. 11 (Mitchell and Chandler, 1939).

All 24 species studied made a significant response to nitrogen applications in terms of increased radial growth. For certain species, such as yellow-poplar, basswood, and ash, the increase in radial growth was on the order of 300 percent. These species were classed as "nitrogen demanding." At the low end of the response scale, and classed as "nitrogen deficiency tolerant," were such species as the oaks, trembling aspen, and red maple. The other species--mainly hickory, sugar maple, beech, blackgum--were classed as intermediate in this respect. Fertilization with nitrogen did not result in an increase in epicormic branching immediately following treatment or later.

As shown in figures 1, 2, 3, and 4, a high degree of correlation was also found between available nitrogen supply and the nitrogen content of the leaves. Here, again, there were differences between species. From the experimentally established relationships between nitrogen supply and the nitrogen content of the leaves, it was possible to develop a standard of comparison, or rating scale, and a technique for using foliar analysis to estimate available nitrogen levels in forest soils of unknown fertility. Using this technique, 50 forest sites throughout the North-east were rated according to nitrogen-supplying capacity. The results are shown in figure 5. It appears from the data obtained from this preliminary survey that the soils of the Black Rock and Arnot Forest study plots rank at the lower end of the distribution curve for relative nitrogen supply. This no doubt accounts for the significant response of all species to nitrogen fertilizer.

It occurred to Dr. Chandler and me at the time that the wood produced by our faster growing trees might be abnormal in some respect or even unsuitable for traditional uses or products. We were not equipped to make such evaluations ourselves, so we quite naturally wrote to the Forest Products Laboratory in Madison to enlist their interest and cooperation. Certainly they would recognize the importance of our research and provide the needed help.

I'll never forget the reply we received soon thereafter. In extremely polite language it said, in effect, that they had more important matters to attend to, and that the answer was no. This reaction was typical of the times. There was very little interest or research in the whole area of forest soils, tree nutrition, wood quality, and the like, and such work was largely confined to a few of the older eastern universities. Industry at that time couldn't have cared less. Even the U.S. Forest Service, although mildly interested, had no program of consequence and didn't make a substantial commitment until the mid-1950's. The odds against developing strong interest in and continued financing for further research in this area appeared to me to be insurmountable. So, with much regret, I tossed in the towel, abandoned my chosen field of specialization, and sought employment elsewhere. Dr. Chandler did likewise soon thereafter, probably for much the same reasons.

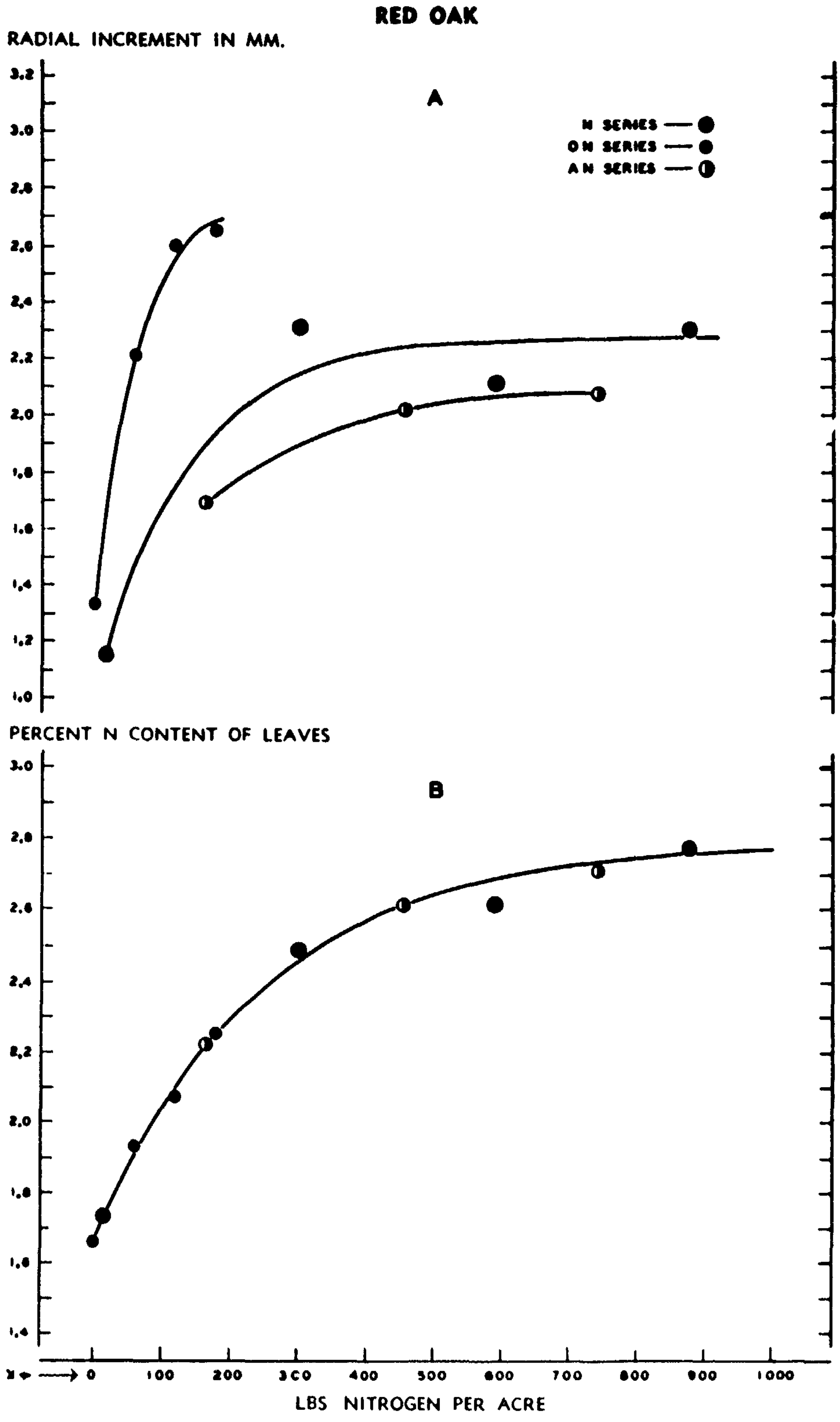

Figure 1.--The relationship between nitrogen supply and the annual radial increment and the nitrogen content of the leaves of red oak trees growing in even-aged stands of mixed hardwoods.

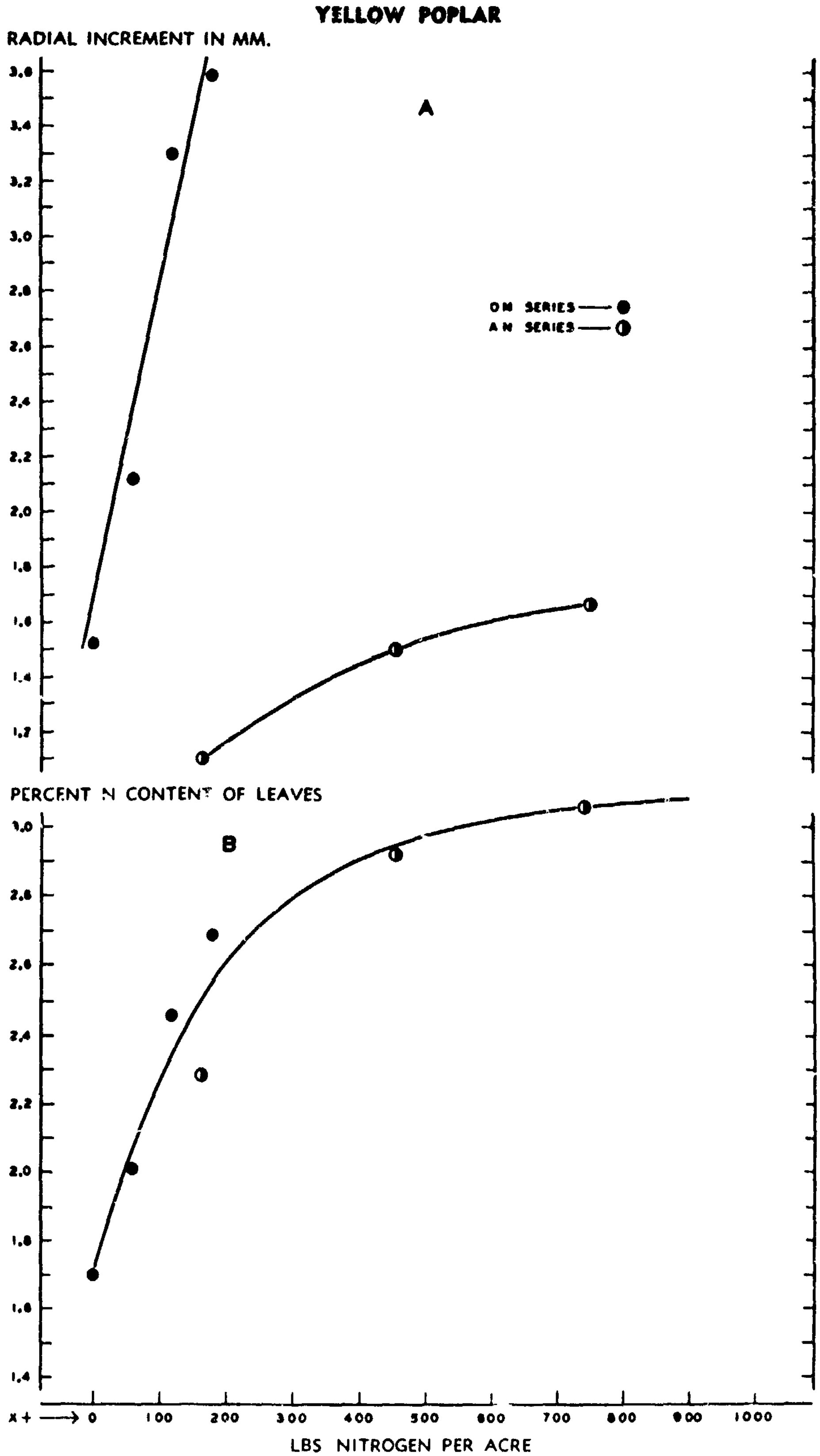

Figure 2.--The relationship between nitrogen supply and the annual radial increment and the nitrogen content of the leaves of yellow-poplar trees growing in even-aged stands of mixed hardwoods.

(M 139 472)

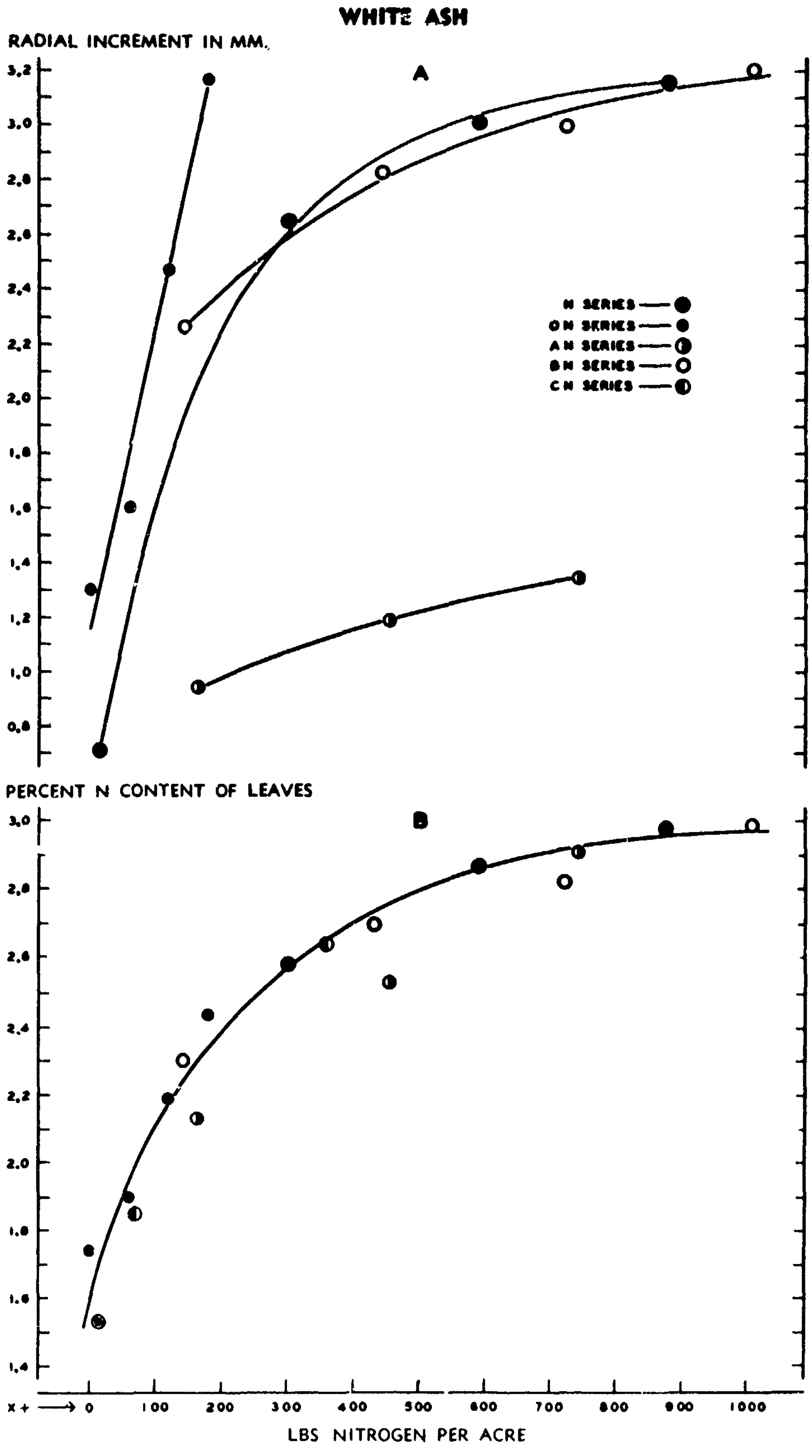

Figure 3.--The relationship between nitrogen supply and the annual radial increment and the nitrogen content of the leaves of white ash trees growing in even-aged stands of mixed hardwoods.

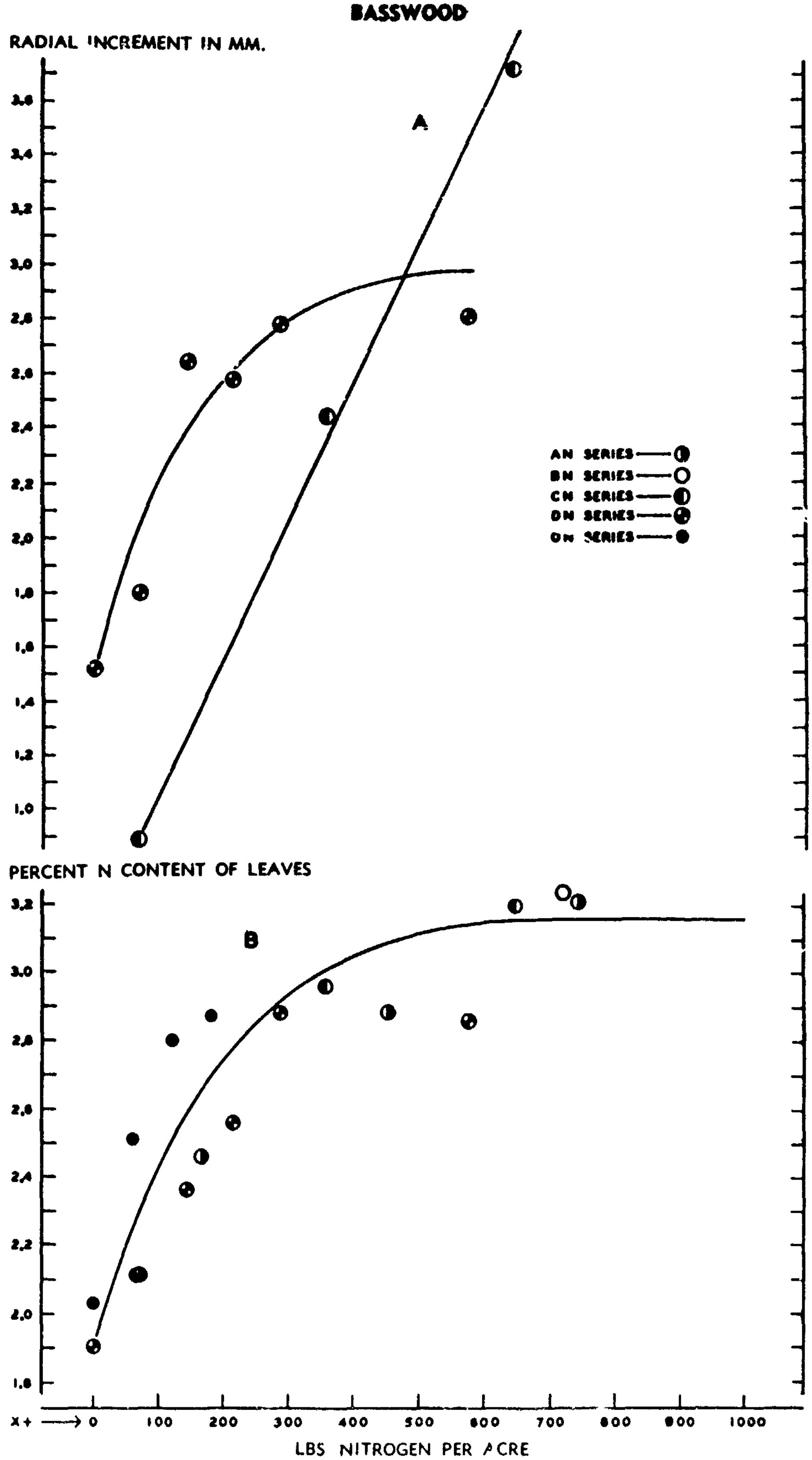

Figure 4.--The relationship between nitrogen supply and the annual radial increment and the nitrogen content of the leaves of basswood trees growing in even-aged stands of mixed hardwoods. (M 139 473)

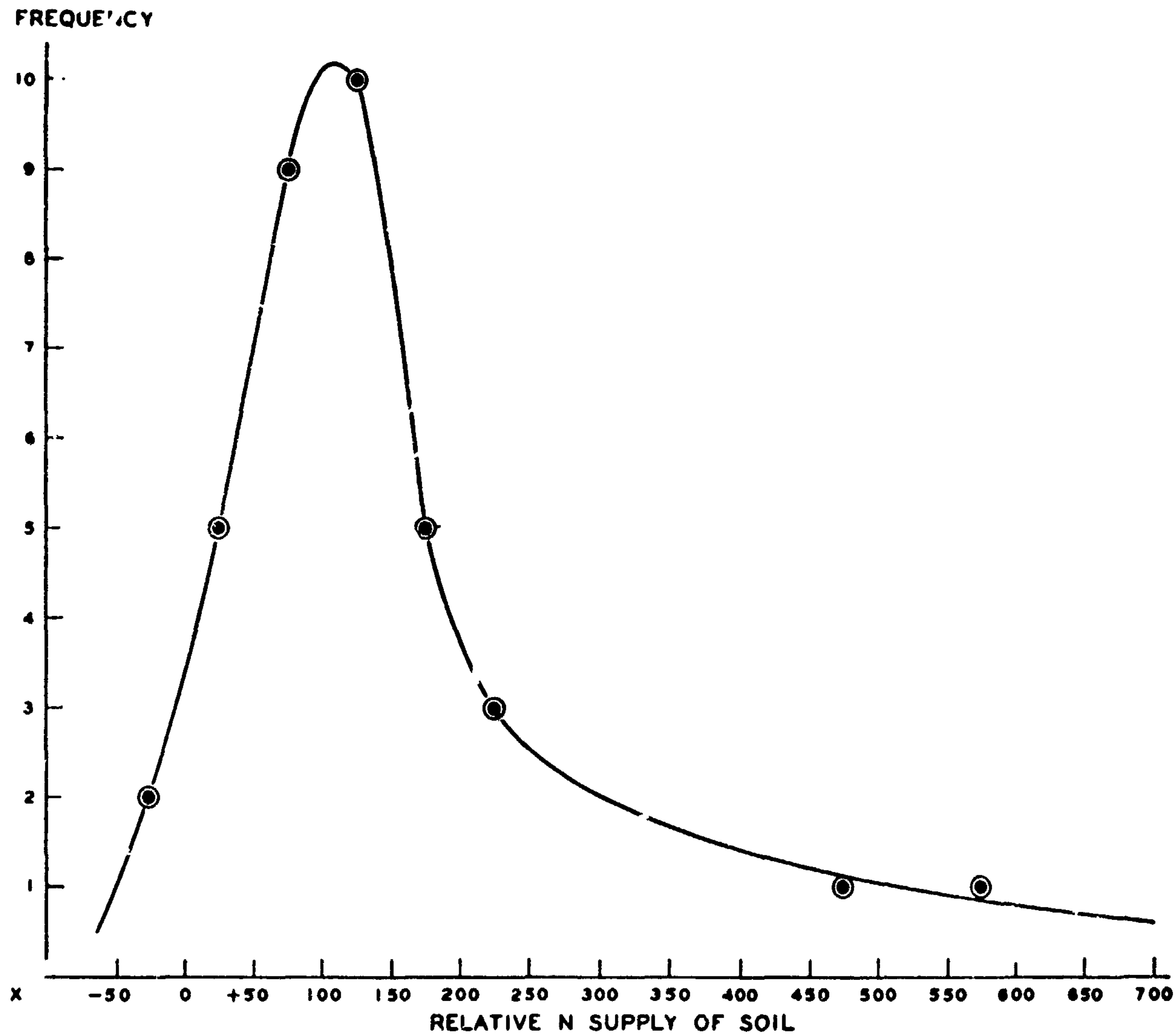

Figure 5.--The frequency distribution of 50 different forest sites throughout the Northeast classified according to relative nitrogen supply.

(M 139 470)

It was not until 27 years later, after I was well settled in my present job at the Forest Products Laboratory, that I was again in a position to followup on, and in certain respects to complete, the research I had initiated so many years earlier. We contacted Harvard University and were granted permission to cut as many sample trees from the old nitrogen plots as we felt necessary to assess the long-term effects of accelerated growth on wood quality. In all, 71 sample trees were selected and felled, including 31 white ash, 28 red oak, and 12 yellow-poplar. Unfertilized control trees were of course included in the sample. All were in the dominant crown class and, for the same species within a variously fertilized series on the same site, an effort was made to sample trees of approximately the same age.

A 2-1/2-inch-thick disk was sawn from the bole of each sample tree 3 feet 8 inches above the ground level and another at 16 feet 2 inches above the ground level. In addition, a 5-foot-long bolt was cut immediately above the lower disk. Both disks and the bolts were shipped by truck to the Forest Products Laboratory for study (fig. 6).

At the Laboratory sawmill, four 4-foot-long boards, each 1-1/4 inches thick and 3 inches wide, were sawn from each sample bolt, one board from each face. Each flat-sawn board was so cut that the inner tangential surface included the first growth ring following the year of fertilization. The boards were dried and conditioned to 12 percent moisture content and rough surfaced to 27/32-inch thickness. Each board was then cut into four 12-inch-long pieces for machining and other tests.

Our primary objective was to determine whether or not wood produced by trees so stimulated with nitrogen was as suitable as average (untreated) wood for the products and uses normally made of these valuable hardwoods. This includes furniture, millwork, paneling, and the like.

Machining properties are probably the most useful and commonly used index to the suitability of wood for such products. Specific gravity, which is related to strength, and toughness, the ability to absorb shock, are also important. Accordingly, all sample material was checked for specific gravity and toughness and subjected to machining tests. The latter were made according to standard methods developed by Davis (1958), and included planing, turning, and shaping (fig. 7).

The office report on this study contains numerous tables that summarize the thousands of observations made, and also the results of rigorous statistical analysis. This tabular material and the statistical data are not included in my paper because the essential findings resulting from all this work are rather meager and can be simply stated as follows:

1. No significant differences were found between the machining properties of wood produced by trees whose growth was greatly stimulated with nitrogen fertilizer and wood produced during the same period by slower growing control trees of the same species growing on the same site.

Figure 6.--Loading sample bolts into truck for transport to the Forest Products Laboratory.

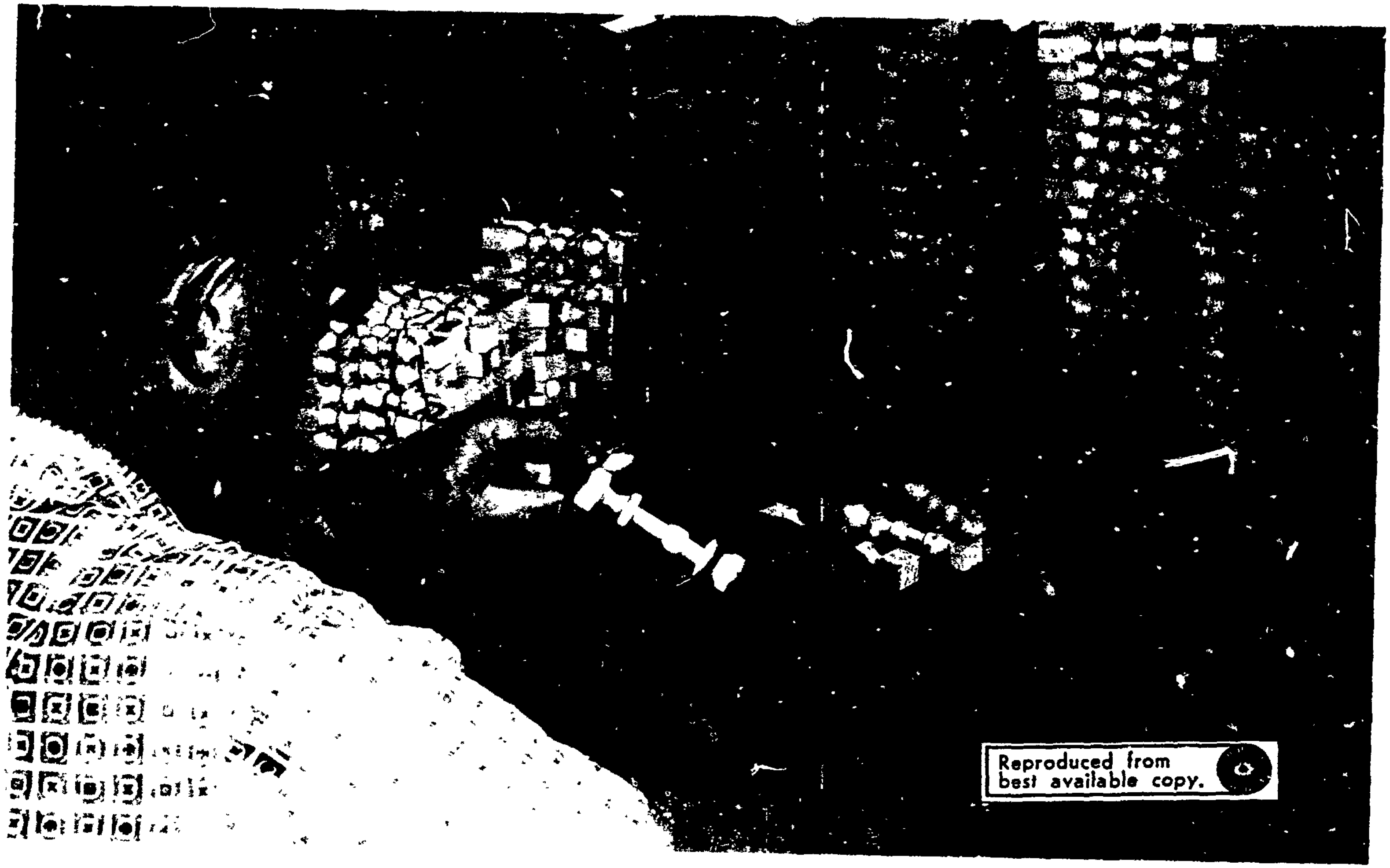

Figure 7.--Dr. George Englerth checking turning test specimens for defects.

(M 127 253)

2. Where valid comparisons could be made, there was a trend toward increasing specific gravity with increasing growth rate.

3. There was a highly significant linear correlation between specific gravity and toughness.

4. One of the most interesting findings was that the growth response to the single application of nitrogen continued for 6 to 8 years (fig. 8). Had the stand been thinned 3 to 4 years following fertilization, the effects on growth acceleration might have continued even longer.

5. Examination of disks cut from fertilized trees at 3 feet 8 inches and 16 feet 2 inches above ground level showed the same general pattern of growth response. The only difference was that the annual rings at the higher level were slightly narrower than the same year's growth nearer the ground level.

6. Only three of the 24 species studied were sampled for wood quality evaluation. It is probably unlikely that the response of the other species to growth acceleration would be greatly different. However, the original fertilizer plots are still intact, and if anyone is interested in pursuing the matter further, I am quite sure that satisfactory cooperative arrangements for so doing could be made with Harvard University.

7. As to utilization for pulp and paper products, assuming anyone would choose to so use prime sawlogs of such valuable hardwoods, the slight trend toward increasing wood density, due largely to thicker cell walls, should be an advantage. It would result in higher pulp yield per unit volume of wood.

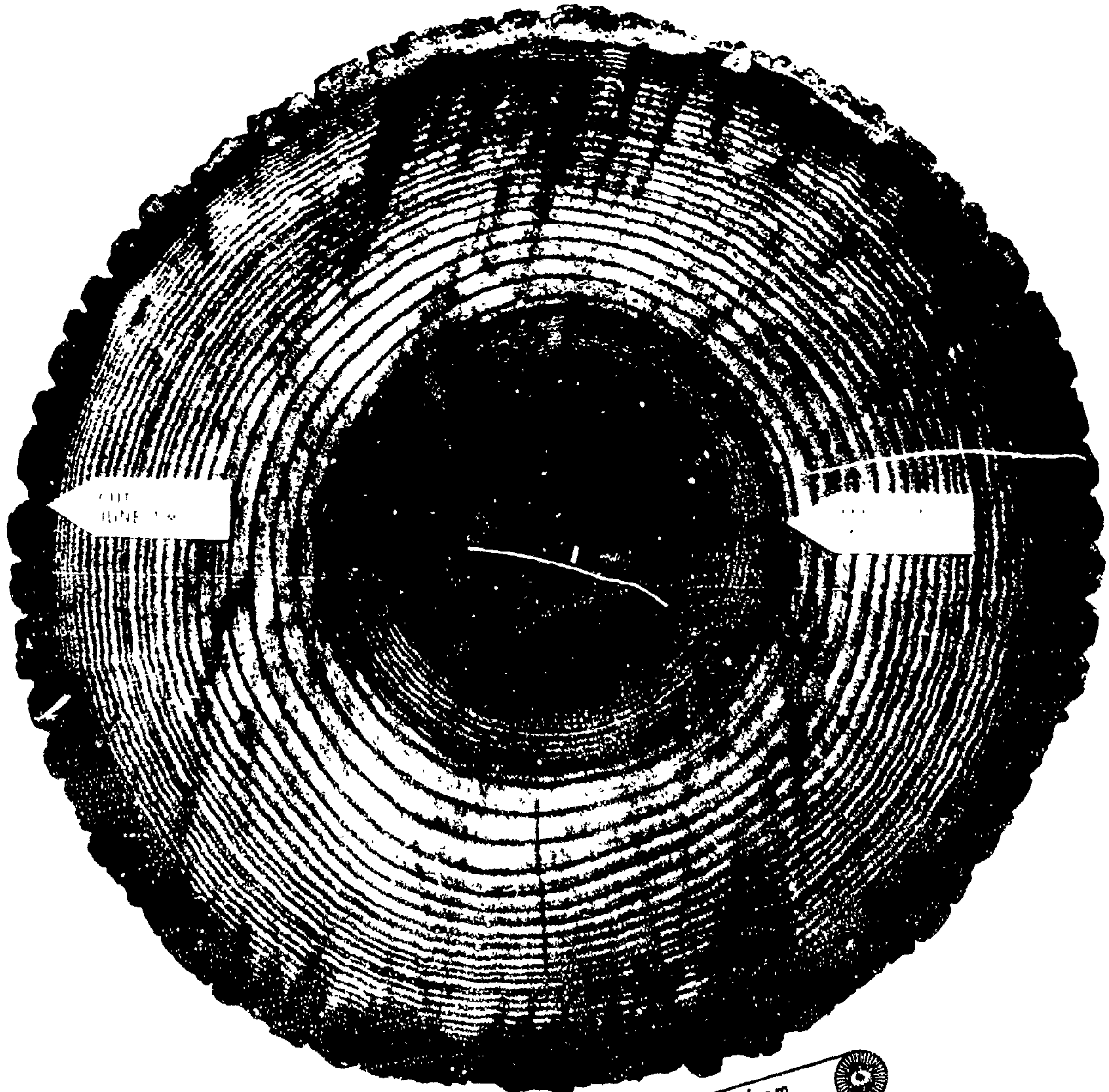

Figure 8.--Cross section (at breast height) from ash tree that was fertilized with nitrogen in May 1935 and cut in June 1962.

(M 130 132)

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Acknowledgments

I wish to thank Harvard University for granting permission to remove 71 sample trees from the old Harvard Black Rock Forest nitrogen fertilizer plots. Special thanks are also due Jack Karnig, in charge of the Harvard Black Rock Forest, and Raymond F. Finn, formerly assistant director of the Forest, and now with the North Central Forest Experiment Station, for assistance in relocating the old plots and helping with arrangements for the selection and removal of sample trees. Several members of the Forest Products Laboratory staff participated in the study, and their contributions are hereby gratefully acknowledged. Kent McDonald had direct charge of logging operations and the transport of sample material, and also handled various phases of the laboratory analysis. M. Y. Pillow (now retired) assisted with the planning and the sampling and had overall supervision of the laboratory work. George Englerth (now retired) conducted the machining tests and prepared the comprehensive office report.

* * *

Bengston, TVA--Two of our previous speakers presented data which showed that fertilization treatments might in some way affect the quantity of intermediate wood that was produced in two coniferous species. If this wood were used for structural pu poses or other than pulp and paper, what might be the effect of increasing the proportion of this intermediate wood? In general, would this be good or bad?

Mitchell--You get more uniformity; and in structural lumber I'd say that would be a big advantage. One of the reasons lumber is so poorly used is that everything has to be overdesigned to take care of the weaker pieces that get in the mix. Now there are two approaches to that. One is nondestructive testing of each individual piece, so that it is assigned a strength value that has reliability and you know how to use it properly. The other approach would be anything that geneticists or silviculturalists could do to get more uniformity. Certainly more uniformity would be a big advantage for structural lumber, for structural plywood, and probably for pulp and paper.

Thor, University of Tennessee--I was impressed by the last slide showing the tremendous response to fertilizer. Wouldn't you experience some kind of failure at a point like that when you are sawing or machining it to a shape or anything like this?

Mitchell--No, we didn't. That would be a reasonable assumption and we particularly checked it. Now the bulk of our machining tests were taken well into the next ring, but we checked that one out, too.

* * *

Gordon--That last paper for this afternoon's program is entitled "Related Aspects of the Morphology of Loblolly Pine and Papermaking." It is coauthored by A. C. Barefoot, R. G. Hitchings, E. H. Wilson, and R. C. Kellison. The paper will be presented by Dr. Bruce Zobel who is known to all of us. He is professor of forest genetics at North Carolina State University and director of the North Carolina State University Cooperative Tree Improvement Program, which is the first of its kind in the United States. Dr. Zobel:

RELATED ASPECTS OF THE MORPHOLOGY

OF LOBLOLLY PINE AND PAPERMAKING

by

A. C. BAREFOOT[1]

R. G. HITCHINGS

E. H. WILSON

R. C. KELLISON

Introduction and Objectives

In recent years several investigators have studied the morphology of southern pines and have attributed observed pulp and paper properties to the wood and tracheid characteristics of the trees (Barefoot, Hitchings, Ellwood, et al., 1964, 1965, 1966, 1970; Wangaard, 1966; Dinwoodie, 1965; McMillin, 1969). In most of this research the properties of the original pine tracheids, the paper fibers, and the resulting paper have been the ones of primary interest.

Our previous studies, Wangaard's, and those summarized by Dinwoodie (all cited above) have suggested the existence of a strong influence of the cell wall thickness--or a measure of density--on many of the properties of paper made from coniferous species. Tracheid length, while having an effect upon some properties, was not shown to be the dominant character that so many of us expected. A portion of this paper will cover some of our most recent work on 23 preselected loblolly pine trees, the results of which clearly establish for loblolly pine the trends uncovered in our earlier work.

It is well known that during pulping and refining (beating), the original tracheid structure is altered considerably in developing the final paper fiber. That fiber, so created, is obviously a major determinant of the properties of the paper. To our knowledge, the role of the original cell characteristics in refining pine "fibers" is not so well documented; pulp researchers most concerned with studying the refining process for wood fibers have largely concentrated on understanding the effects of the process on the fibers or on understanding the effects of the refined fibers on the paper made from them. Emerton (1965), Gallay (1958), Giertz (1958), Higgans and de Yong (1962), Dadswell and Watson (1962), Wardrop (1963), and Norberg (1971) have been contributors to this work. While some of the botanically oriented among these workers have spoken of wood morphology and refining (Dadswell and Watson,

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[1]Authors are from North Carolina State University and are, respectively: Professor of Wood and Paper Science; professor of Pulp and Paper Technology; research assistant; and associate director, Cooperative Programs.

1962; and Wardrop, 1963), most of the researchers are "pulpmakers" and have been concerned with the morphological condition of the fiber after refining. For these reasons, we shall introduce a part of our preliminary studies on the role which the cell morphology of tracheids plays in affecting the properties of refined fibers. We shall also present some of the correlations we obtained between the growth of our trees and certain of their wood and tracheid qualities. Finally, we shall discuss some of the industrial implications of our studies on the kraft pulping of southern pines.

Material and Procedures

The trees for this study were chosen from among over 2,000 loblolly pine trees previously characterized by the Cooperative Tree Improvement Program at North Carolina State University as being straight of bole and free of excessive limbs. Trees with high and low specific gravities, long and short tracheids, and of a young or old age were sought and obtained in the Coastal Plain and Piedmont regions between southern Georgia and the Virginia peninsula (fig. 1).

The trees were cut into 5-foot bolts and delivered to the Laboratory where the bolts were immediately weighed, sampled, debarked, and reweighed. Disks for moisture content determinations, specific gravity, and fiber characterization were taken at the 4.5-foot level and at the top and bottom of each 5-foot bolt.

The bolts were separated into wood fractions representing the inner 0-10 ring zone, the 10-35 (approximately) ring zone, and an outer + zone, when it contained sufficient wood for pulping. For some trees, the entire bole of the crown, or top was also pulped. Since the young trees were between 10 and 20 years of age, the whole tree was pulped without separating out the inner zone, the juvenile core.

The tracheid or wood characteristics determined on a weighted basis for each zone or fraction of the wood were:

1.	Unextracted specific gravity	USG
2.	Extracted specific gravity	ESG
3.	a. Summerwood percentage, by volume V% SU or	SU
	b. Summerwood percentage, by estimated weight	W% SU
4.	Springwood tracheid length	SpFL, mm.
5.	Springwood cell wall thickness (radial)	SpCW, µm.
6.	Springwood lumen diameter (tangential)	SpCL, µm.
7.	Springwood cell diameter (tangential)	SpCD, µm.
8.	Summerwood tracheid length	SuFL, mm.
9.	Summerwood cell wall thickness (radial)	SuCW, µm.
10.	Summerwood lumen diameter	SuCL, µm.
11.	Summerwood cell diameter	SuCD, mm.
12.	Tree tracheid length (combined springwood and summerwood)	TTL, mm.
13.	Tree cell wall thickness (combined springwood and summerwood)	CW, µm.
14.	Tree lumen diameter (combined springwood and summerwood)	CL, µm.
15.	Tree cell diameter (combined springwood and summerwood)	CD, µm.

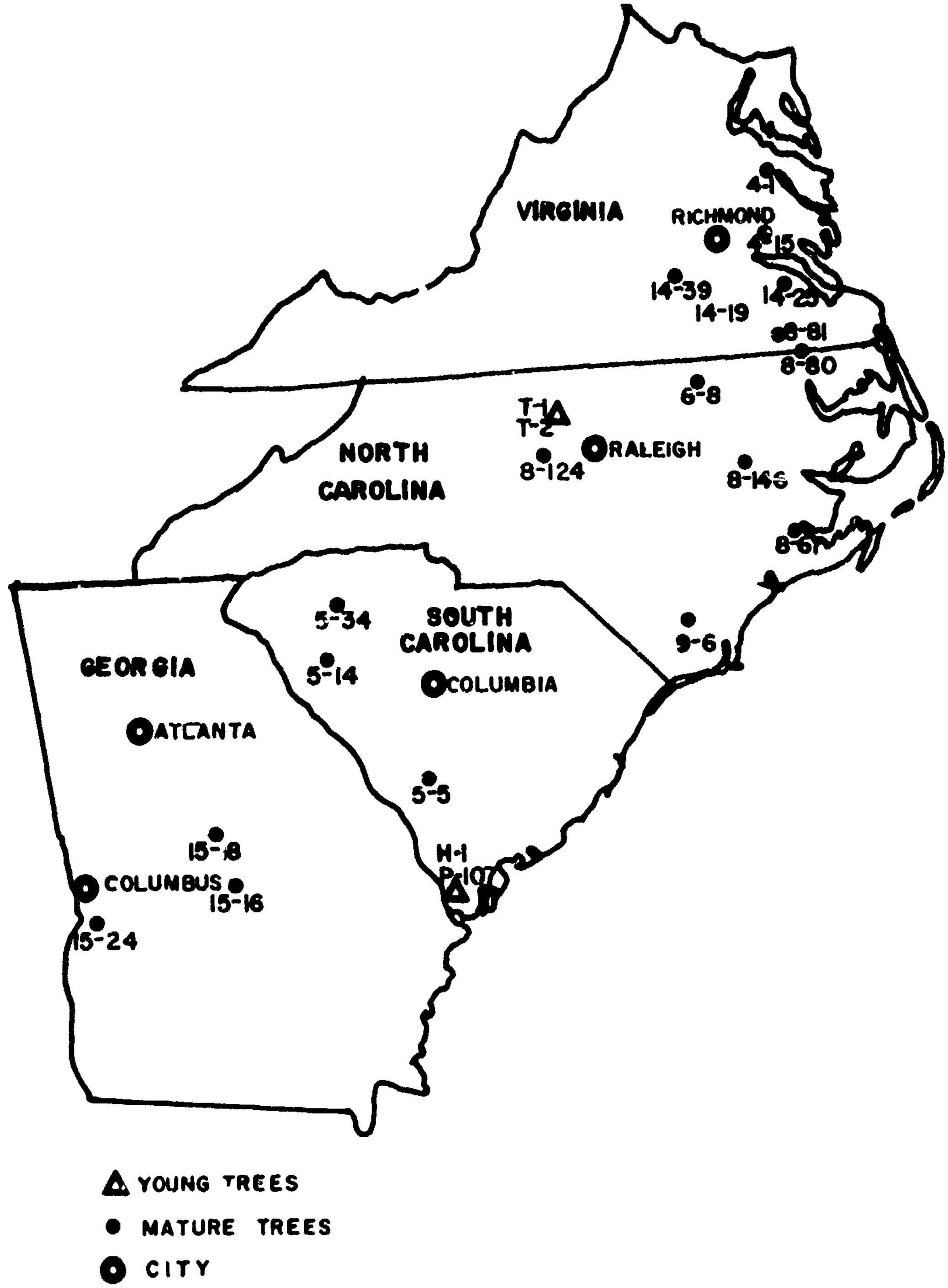

Figure 1.--Geographical location of the trees in the study.

Key to company numbers

a) 4 - Chesapeake Corporation of Virginia
b) 14 - Continental Can Company, Incorporated
c) 6 - Albemarle Paper Company
d) 8 - Weyerhaeuser Company
e) 9 - Riegel Paper Corporation
f) 5 - Continental Can Company, Incorporated
g) 15 - Georgia Kraft Company
h) T - North Carolina State University (young trees)
i) H - Continental Can Company, Incorporated (young trees)

glycerine/water mounts of fibers macerated in a 1:1 glacial acetic acid-hydrogen peroxide solution. Sufficient numbers of fibers were measured for each variable to give an average which should be within ±5% of the true average.

The paper properties recorded were:

Beating Time	= BT
Canadian Standard Freeness	= CSF
Apparent Density	= AD
Burst Factor	= BF
Breaking Length	= BL
Tear Factor	= TF

Because the extent and timing of the projects for relating tracheid properties to beating were not predetermined, the decision was made to save the dry handsheets for these purposes rather than store wet, undried fibers in jars. This, in retrospect, was probably unfortunate, inasmuch as the paper required remacerating for the subsequent fiber studies.

The remacerating was done by placing small sections of the selected handsheets in vials containing a 10% solution of NaOH at room temperature and mechanically agitating sufficiently to cause fiber separation. This agitating process may have exerted unknown effects on the qualities of the paper fibers. Since no papers were produced from fibers at 0 minutes' beating time, a gap now exists in what would have been desired data coverage. The data for fibers produced at 5 to 125 minutes' beating time are reported in this paper. The fibers were stained with 1% aqueous safranin and mounted in 50/50 water and glycerine for examination.

The data relating the paper fiber characteristics to original morphological qualities of the tree and to resulting paper properties were analyzed principally by regression techniques.

The paper fiber qualities selected for study were:

1. Fiber length = APFL, mm.
2. Broken fiber percentage = PBF, %
3. Unbroken fiber percentage = PUF, %
4. Fiber diameter = FD, μm.
5. Cell wall layer separation = CWS, %
6. Fiber width = FW, μm.

In this paper only fiber length will be considered. Briefly, however, the procedures for making the above measurements involved making slides and projecting images onto a flat paperboard surface for measurement by a tracing wheel connected to an electronic counter. In the projects, 100 fibers (broken and unbroken combined) were measured to determine the average length. Any element shorter than 0.1 millimeter was classified as fines and was not measured.

A more detailed discussion of these procedures is given by Parham (1968) and Barefoot et al. (1970).

Results and Discussion

Comparative data on averages for 16 of the 23 trees are given in tables 1 and 2. These 16 trees formed the sample base of core and outer wood for a duplicated comparison of the four combinations of high and low density woods with long and short tracheids. Three older trees having outer + wood and the four young trees are not represented in these tables. However, an examination of the data for these individuals revealed that their values fell within those of the comparable zones, core, and outer, in the 16 trees. These values are not the result of randomly selected samples and thus may not reflect any true growth or geographical patterns. For example, in tables 3 and 4 the specific gravity for both the core and outer wood of the Coastal Plain trees and the Piedmont trees is shown to be essentially equal. Since the 16 trees were deliberately preselected from the CTIP data on the basis of known combinations of density and tracheid lengths, such a result would not be unusual.

However, the percentage of summerwood in the core wood of the Piedmont trees was greater than found in the core wood of the Coastal Plain trees. Likewise the total percentage yield of the high kappa number pulps was greatest in the Piedmont core woods. The greater summerwood may have been accidental but we feel the yield results were not. Gladstone et al. (1970) presents information from a more basic study which suggests that the percentage of summerwood significantly affects yield, particularly when high lignin content pulps are considered. However, while the differences in the averaged data for the outer wood for both specific gravity and summerwood still follow the same patterns as for core wood, the actual differences are so small that no conclusions can be made.

For the high kappa number pulps, the results of this study provide convincing data that the percentage yield is greater from woods of higher density. The results are summarized in table 5. Note that the percentage of summerwood (+) always had the highest R value and thus accounted for more of the variation in the original data than any other measure of density. Nevertheless, it can also still be said that woods of higher specific gravity can be expected to have higher percentage yields of pulp. Obviously, increases in specific gravity may come from appropriate changes in cell dimensions or from an increase in the quantity of summerwood.

For the low kappa number pulps, no morphological factor or factors could be associated with total yield percentage. Gladstone et al. (1970) working with small bomb cooks found the yield differences in pulps prepared to a higher degree of purity to be very small. Therefore, the variation in the data coming from our larger 3,000-gram cooks very likely was sufficiently large to mask any morphological associations, even where they truly exist. Since in the high kappa number pulps the percent of summerwood has a greater effect in the core wood than in the outer wood (see fig. 2, and compare the slope model 1.2 with that of model 1.4 in table 5), one could suggest that the total yield of high kappa number pulp from loblolly pine is a nonlinear function of percent summerwood. A rapid rise in total yield (slope = 0.48) occurred in the summerwood percentages of the cores and a lesser rise (slope = 0.19) in the percentages for the outer wood. This evidence suggests that, upon providing for the level of polysaccharide originally present and the nonlinear response of the variables, the R value for a model could be greatly

Table 1. The range and averages for springwood and summerwood fiber morphology measured with the radial side of the macerated fiber facing up. (Excluding young trees)

Springwood Fiber Morphology

	Core			Outer		
	Low	Avg.	High	Low	Avg.	High
Cell Wall, μm.	4.56	4.85	5.12	4.65	5.02	5.48
Cell Lumen, μm.	35.29	37.52	42.26	39.05	43.47	48.05
Cell Diameter, μm.	44.92	47.21	51.76	49.84	53.50	57.67
Tracheid Length, mm.	2.86	3.15	3.33	3.69	4.23	4.70

Summerwood Fiber Morphology

	Core			Outer		
	Low	Avg.	High	Low	Avg.	High
Cell Wall, μm.	9.18	11.13	11.91	10.53	12.30	13.41
Cell Lumen, μm.	14.69	17.78	20.99	14.30	17.58	22.31
Cell Diameter, μm.	35.65	40.03	42.18	37.46	42.17	44.64
Tracheid Length, mm.	3.15	3.44	3.87	3.87	4.37	4.89

Table 2. Morphological averages of 16 selected Coastal Plain and Piedmont trees (Excluding the young trees)

		High Density	Low Density	Long Fiber	Short Fiber
CTIP[1/]	Mature Wood	0.58	0.47	0.54	0.51
Unextracted Sp. Gr.	Core	0.44	0.40	0.43	0.41
	Outer	0.51	0.45	0.49	0.47
Extracted Sp. Gr.	Core	0.43	0.38	0.41	0.40
	Outer	0.51	0.44	0.48	0.46
Tree Cell Wall, μm.	Core	6.87	6.29	6.69	6.47
	Outer	8.42	7.65	8.24	7.83
Spring Cell Wall, μm.	Core	4.97	4.72	4.88	4.81
	Outer	5.17	4.87	4.99	5.05
Summer Cell Wall, μm.	Core	11.22	11.03	11.17	11.08
	Outer	12.31	12.28	12.54	12.05
Tree Cell Lumen, μm.	Core	30.51	33.66	31.31	32.86
	Outer	30.53	35.22	32.30	33.25
Spring Cell Lumen, μm.	Core	36.51	38.53	36.94	38.10
	Outer	41.89	45.03	43.97	42.96
Summer Cell Lumen, μm.	Core	16.75	18.81	17.16	18.39
	Outer	16.53	18.63	16.51	18.53
Tree Cell Diameter, μm.	Core	44.25	46.25	44.69	45.81
	Outer	47.16	50.52	48.78	48.91
Spring Cell Diameter, μm.	Core	46.46	47.98	46.69	47.75
	Outer	52.22	54.77	53.94	53.05
Summer Cell Diameter, μm.	Core	39.18	40.87	39.50	40.55
	Outer	41.14	43.19	41.71	42.62
CTIP[1/] Fiber Length, mm.	15-year ring	3.62	3.66	3.91	3.37
	30-year ring	4.53	4.42	4.91	3.97
Tree Fiber Length, mm.	Core	3.23	3.23	3.22	3.23
	Outer	4.28	4.28	4.47	4.09
Spring Fiber Length, mm.	Core	3.16	3.13	3.12	3.17
	Outer	4.25	4.20	4.43	4.02
Summer Fiber Length, mm.	Core	3.41	3.47	3.48	3.40
	Outer	4.34	4.39	4.53	4.19

[1/] Breast high values from Cooperative Tree Improvement Program

Table 3. Comparison of wood and paper properties for trees[1/] of the Coastal Plain and Piedmont (high Kappa Number pulps, and excluding young trees)

	WOOD PROPERTIES					PAPER PROPERTIES			
	Early-Late Combined		Latewood Only			500 ml csf		300 ml csf	
	Coastal Plain	Piedmont	Coastal Plain	Piedmont		Coastal Plain	Piedmont	Coastal Plain	Piedmont
				10-YEAR (CORE)					
ESG	0.403	0.407			BT	83.04	76.86	115.61	105.99
CW	6.4	6.8	10.8	11.5	AD	.528	.505	.591	.555
CL	31.7	32.5	18.0	17.5	BF	72.42	66.57	880.09	73.37
CD	44.4	46.0	39.6	40.5	BL	9638	8985	10751	9946
FL	3.25	3.21	3.46	3.42	TF	9.14	10.35	7.86	8.96
V% SU	26.3	30.1							
W% SU	40.1	4 .4							
				10-35 YEAR (OUTER)					
ESG	0.470	0.474			BT	77.91	76.22	104.61	102.81
CW	7.9	8.2	12.1	12.5	AD	.478	.457	.525	.499
CL	32.5	33.0	18.0	17.1	BF	67.49	63.19	75.17	71.75
CD	48.3	49.4	42.2	42.2	BL	8592	8299	9561	9227
FL	4.29	4.27	4.40	4.33	TF	12.84	14.32	10.77	12.03
V% SU	41.6	42.4							
W% SU	61.5	62.0							

1/ The trees in this study are not from a random sample but a specially selected sample.

Table 4. Comparison of yields and density values for the trees of the Coastal Plain and Piedmont (high kappa number pulps, and excluding young trees)

	Coastal Plain	Piedmont
	10-Year Core	
Extracted Specific Gravity	.403	.407
Percent of summerwood by volume	26.3	30.1
Percent of summerwood by weight	40.1	44.4
Total Yield,%	51.11	54.21
Screened Yield,%	42.56	48.06
Rejects,%	8.55	6.15
	10-35 Year Outer	
Extracted Specific Gravity	.470	.474
Percent of summerwood by volume	41.6	42.4
Percent of summerwood by weight	61.5	62.0
Total Yield,%	55.98	55.61
Screened Yield,%	52.50	52.48
Rejects,%	3.48	3.13

Table 5. Model equations for evaluating the percent total yield of the high kappa number 68

Model Number	Model and Coefficients	d.f.	"t"	R	Significance Probability for R
					Pct.
	Core - 19 Trees: Mean TY = 52.2%				
1.1	TY = 33.57 + 45.68 ESG	17	2.32	0.49	5
1.2	TY = 38.60 + 0.482 SW	17	4.58	0.74	1
	Outer - 19 Trees: Mean TY 55.7%				
1.3	TY = 46.46 + 19.44 ESG	17	1.44*	0.33	NS*
1.4	TY = 47.71 + 0.189 SW	17	1.84*	0.41	7.5
	Core and Outer - 16 Trees: Mean TY = 54.2%				
1.5	TY = 37.10 + 38.05 USG	30	3.90	0.58	1
1.6	TY = 38.15 + 36.69 ESG	30	3.90	0.58	1
1.7	TY = 45.21 + 0.257 SW	30	4.96	0.67	1
	All Fractions - All Trees: Mean TY = 53.2%				
1.8	TY = 36.68 + 37.54 ESG	50	4.80	0.56	1
1.9	TY = 36.34 + 37.29 USG	50	4.54	0.54	1
1.10	TY = 38.23 + 2.02 CW	50	4.98	0.58	1
1.11	TY = 44.93 + 0.230 SW	50	5.24	0.60	1

*Only "t" values having probability levels smaller than 5% for the one tailed test are considered statistically significant.

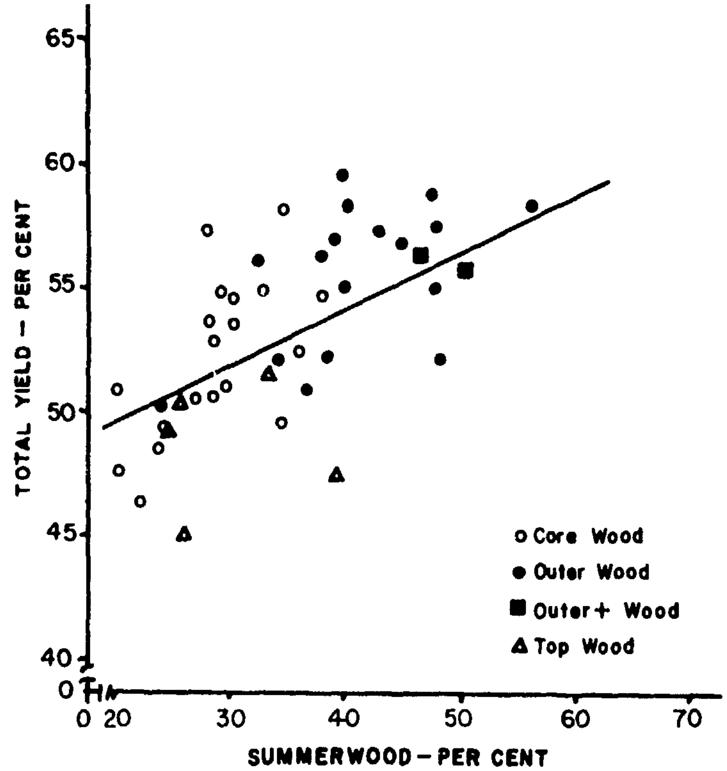

Figure 2.--The influence of the summerwood percent on the total yield of sulfate pulps made at constant active alkali. (Average kappa number 68. Line fitted from model No. 1.11.)

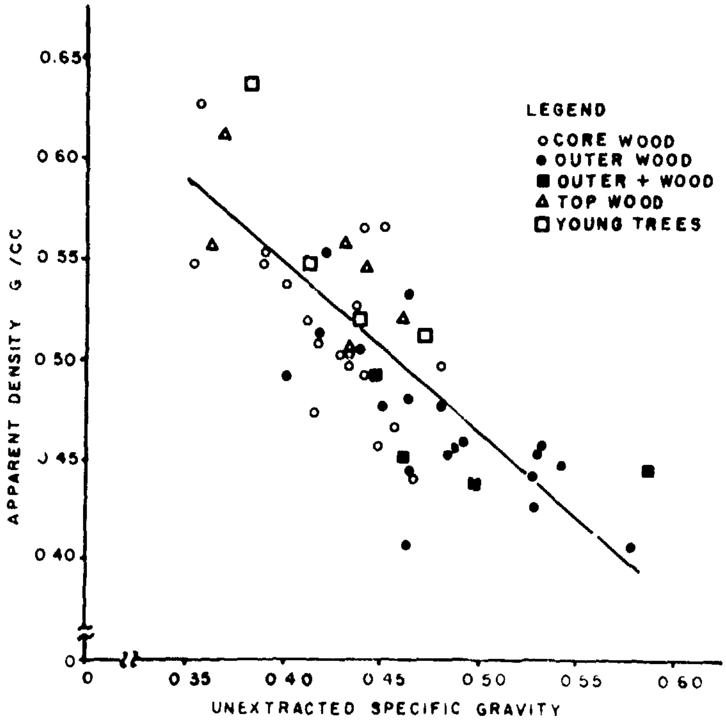

Figure 3.--The influence of unextracted specific gravity on apparent density of high kappa number pulps at 500 millimeters CSF. (All trees included: Line fitted from model 2.2a.)

improved over that of model 1.7. From a statistical standpoint, use of this model resulted in a highly significant R value but it may nevertheless be an insufficient or an incorrect equation.

The addition of other density measures to the model added relatively little to the reduction in variation. When all the trees were treated together. the addition of no other variable to the model containing summerwood percentage increased the R value beyond the 0.6 level; the "t" value of the added variable was never statistically significant.

The percent of summerwood therefore seems to be the morphological feature of prime importance in establishing the percent total yield to be expected from a given lot of wood.

Of the many regressions set up and tested on the basis of morphological models established by Barefoot et al. (1964, 1966), those involving measures of density seemed to be the most consistent predictors of the pulp and paper properties observed in this study. Some of the regressions of the properties on specific gravity, cell wall thickness, and tracheid length for both high kappa number and low kappa number pulps are given in tables 6 and 7. Generally speaking, the trends for either 500- or 300-millimeter CSF and high or low kappa number pulps are the same for any given property. However, the low kappa number pulps and 300-millimeter CSF pulps have lower "t" and R values, probably because of the smaller overall ranges of values resulting from paper fibers being brought to a more uniform and similar condition (Parham, 1968; and Barefoot et al., 1970).

Figures 3 to 7 indicate the relationships of the unextracted specific gravity or cell wall thickness to five pulp and paper properties. From these graphs, it can be seen that as the specific gravity increases, or average cell wall thickness increases, the apparent density of handsheets decreases, burst factor decreases, and tear factor increases. The models for breaking length and beating time shown in tables 6 and 7 indicate that, as the measures of density increase, the time for beating to a given freeness level decreases and at a given freeness level the breaking length, paralleling the reaction of burst factor, also is decreased. Models 2.3c and 2.7c of table 6 and 3.3c of table 7 are included to examine the effect of tracheid length. For tear factor, the original tracheid length seems to have no influence; for burst factor, when combined with cell wall thickness, in models 2.3c and 3.3c, an increased tracheid length seems to have a beneficial effect on burst strength. However, if figure 4 is examined critically, it can also be seen that the longer fibered outer wood and the shorter fibered core wood probably account for these regression relationships. At the same cell wall thickness, say 7.0 microns, the "longer fibered" outer wood has a higher burst (and breaking length) than the "shorter fibered" core wood. Now the question may be raised: Are the differences in burst the result of tracheid length or a difference in the physical or chemical nature of the core and outer cell walls? We don't know. The paper with the highest burst and breaking length came from the thin walled, easily collapsed, better bonded core wood fibers; the paper with the highest tear factor came from the trees with the thickest cell walls. Figure 8 is a summary graph of the effect of the unextracted specific gravity on the five properties mentioned.

Table 6. Model equations for evaluating the pulp and paper qualities of the high kappa number pulps, kappa No. 68 to 500 and 300 millimeters CSF in terms of some morphological characteristics

Model No.	CSF	Model and Coefficients	d.f.	"t"	R	Significance Probability for t & R
	Ml.					Pct.
		ALL WOOD ZONE FRACTIONS FOR ALL TREES				
2.1a	500	BT = 124.0 - 105.4 USG	50	3.62	0.46	1
2.1b	300	BT = 178.3 - 162.6 USG	50	4.44	.53	1
2.2a	500	AD = 0.852 - 0.778 USG	50	8.46	.77	1
2.2b	300	AD = 0.933 - 0.846 USG	50	8.21	.76	1
2.3a	500	BF = 108.8 - 92.5 USG	50	7.49	.73	1
2.3b	300	BF = 106.5 - 70.4 USG	50	5.72	.63	1
2.3c	500	BF = 95.4 - 6.64 CW + 5.48 FL	49	6.98; 3.55	.73	1
2.4a	500	TF = -9.67 + 47.3 USG	50	11.24	.85	1
2.4b	300	TF = -6.55 + 36.6 USG	50	11.05	.84	1
2.4c	500	TF = -6.94 + 2.52 CW	50	13.53	.89	1
2.4d	300	TF = -3.31 + 1.79 CW	50	9.87	.81	1
2.5a	500	BL = 14,367 - 12,063 USG	50	10.95	.84	1
2.5b	300	BL = 15,021 - 11,313 USG	50	9.31	.80	1
		FRACTIONS FROM THE 19 OLDER TREES				
2.6a	500 (core)	BF = 135.3 - 10.1 CW	17	5.28	.79	1
2.6b	500 (outer)	BF = 122.5 - 7.2 CW	17	4.87	.76	1
		CORE AND OUTER WOOD ZONE FRACTIONS FOR 16 TREES				
2.7a	500	TF = -17.36 + 2.60 CW	30	10.82	.89	1
2.7b	300	TF = -5.18 + 2.06 CW	30	9.78	.87	1
2.7c	500	TF = -5.16 + 0.13 FL + 1.99 CW	29	0.22 5.22	.87	1

Table 7. Model equations for evaluating the pulp and paper qualities of the low kappa number pulps, kappa No. 33 to 500 and 300 millimeters CSF in terms of some morphological characteristics

Model No.	CSF	Model and Coefficients	d.f.	"t"	R	Significance Probability for t & R
	Ml.					Pct.
		CORE AND OUTER ZONE FRACTIONS OF 10 OLDER TREES				
3.1a	500	BT = 53.59 - 22.4 USG	18	1.10	0.25	NS
3.1b	300	BT = 91.8 - 59.7 USG	18	1.96	.42	6
3.2a	500	AD = 0.860 - 0.724 USG	18	6.78	.85	1
3.2b	300	AD = 0.929 - 0.774 USG	18	6.57	.84	1
3.3a	500	BF = 92.4 - 71.2 USG	18	3.55	.64	1
3.3b	300	BF - 96.5 - 64.9 USG	18	2.86	.56	5
3.3c	500	BF - 86.4 + 4.61 FL - 6.02 CW	17	1.67 3.91	.72	1
3.4a	500	TF = -7.19 + 39.1 USG	18	9.94	.92	1
3.4b	300	TF = -5.85 + 33.1 USG	18	10.14	.92	1
3.5a	500	BL = 14,143 - 11,636 USG	18	6.06	.82	1
3.5b	300	BL = 14,989 - 11,552 USG	18	5.84	.81	1

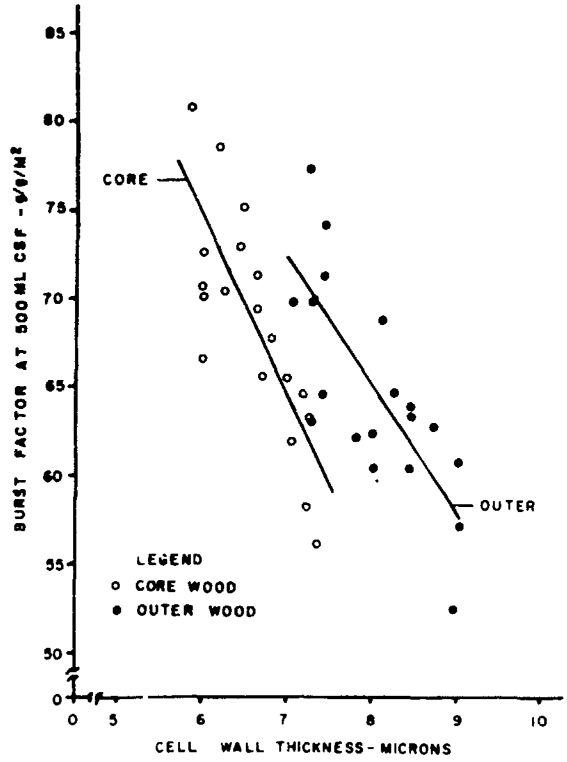

Figure 4.--The influence of cell wall thickness on burst factor at 500 millimeters CSF. (Nineteen trees, kappa number 68: Lines fitted from models Nos. 2.6a and 2.6b.)

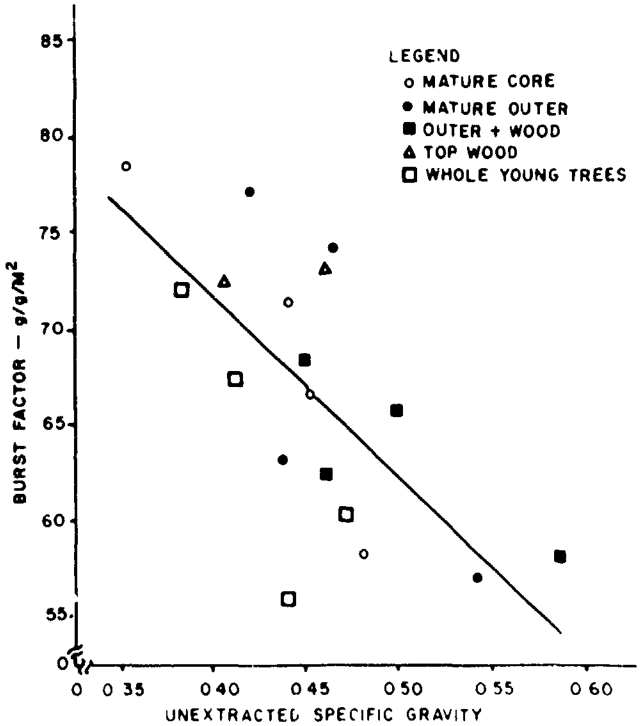

Figure .--The influence of specific gravity on burst factor--comparison of young, mature and top wood for high kappa number pulps at 500 millimeters CSF pulps. (Line fitted from model No. 2.3a.)

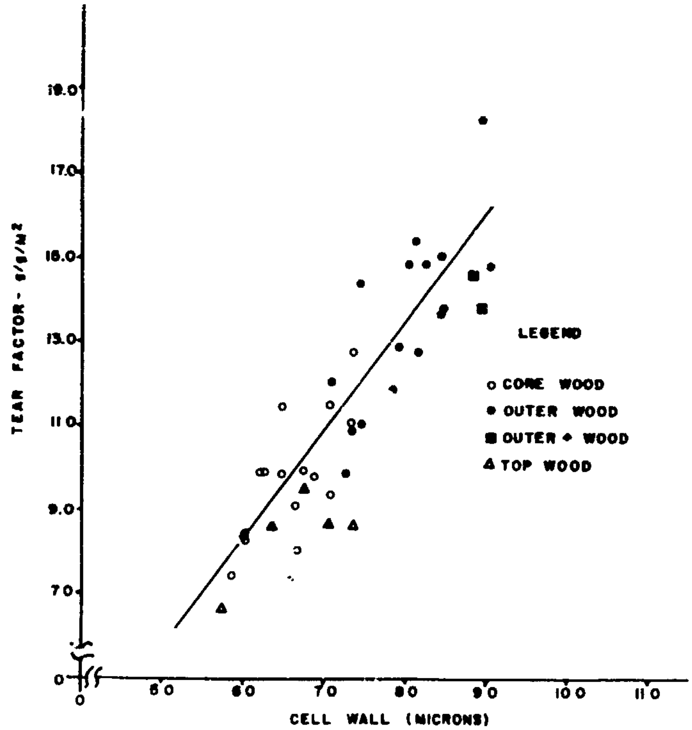

Figure 6.--The influence of cell wall thickness on the tear factor at 500 millimeters CSF. (Sixteen trees included, average kappa number 68: Line fitted from model No. 2.7a.)

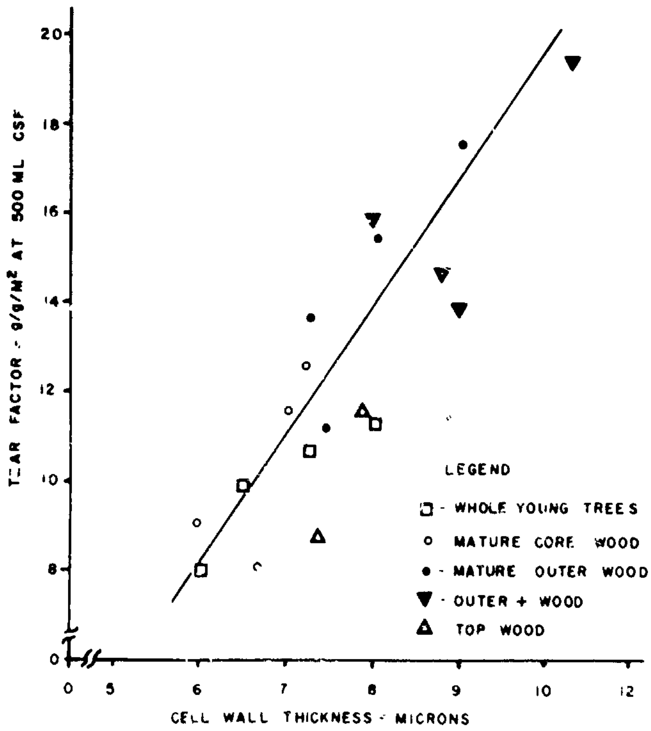

Figure 7.--The influence of cell wall thickness on tear factor of high kappa number pulps at 500 millimeters CSF--comparison of young and mature trees. (Lines fitted from model No. 2.4c for all trees.)

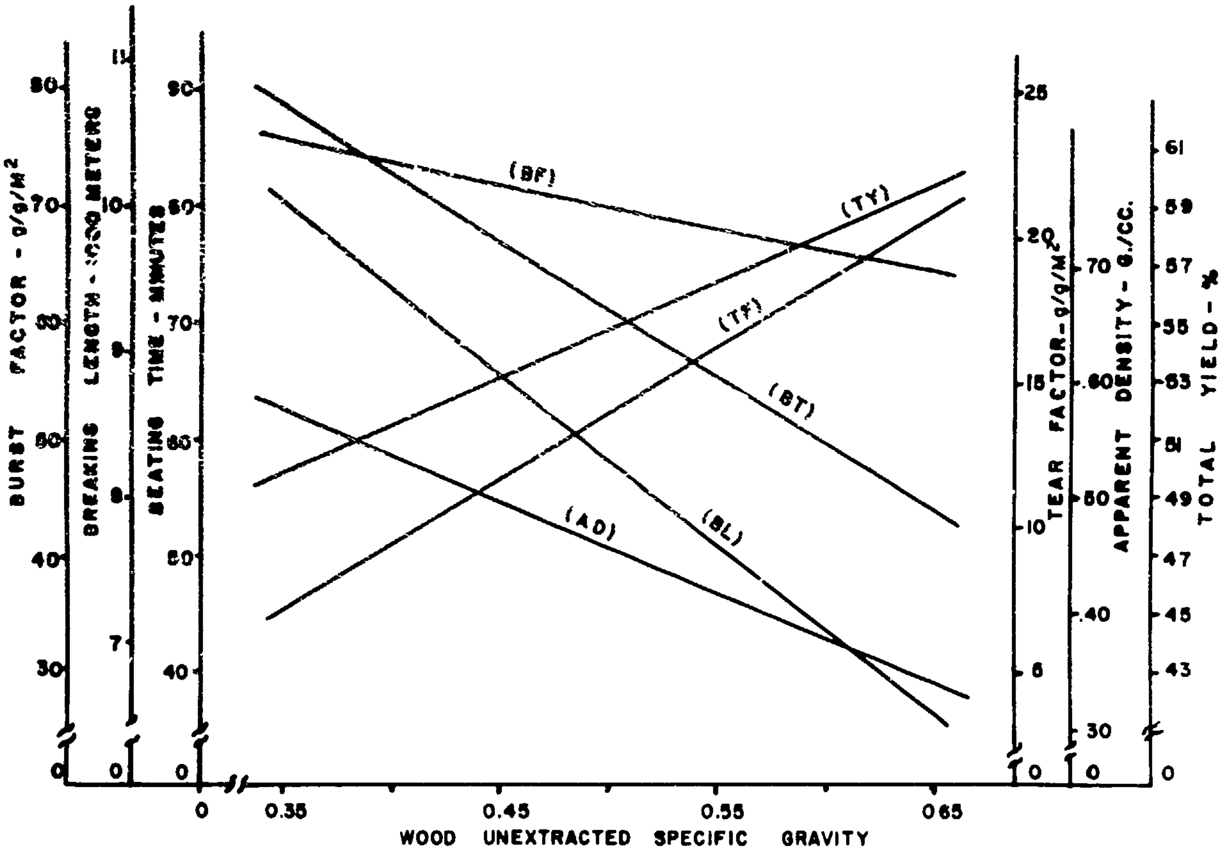

Figure 8.--The effect of wood specific gravity on pulp properties at 500 millimeters CSF. (Based on prediction equations from all trees pulped at 18% A.A.)

(BT) = beating time - R = 0.46, model 2.1a.
(AD) = apparent density - R = 0.77, model 2.2a.
(BF) = burst factor - R = 0.73, model 2.3a.
(TF) = tear factor - R = 0.85, model 2.4a.
(BL) = breaking length - R = 0.84, model 2.5a.
(TY) = total yield - R = 0.49, mode. 1.17.

Burst factor is usually the property of most concern of kraft mills; tear factor is usually of secondary importance. Presumably, therefore, the morphological factors improving burst are of most significance to these mills. For foresters growing wood for these mills, the goal is likely to be either the optimum volume or pounds of wood per year. By planting trees having fast growth rates of high specific gravity wood, the foresters could expect to have the best of both these conditions. To demonstrate that the mills can probably optimize tear and obtain adequate tensile strength, figures 9 and 10 are included. These figures relate the relative development of tear and breaking length during the refining of four fractions having wood of high to low specific gravity. These graphs indicate that, with wood of higher specific gravity, the mills could maintain a higher tear strength while developing increased tensile strengths by longer refining times. The highest tear values cannot be obtained with wood of low specific gravity, but higher tensile strengths of any wood can be developed further by processing. Therefore, there must be a tradeoff point at which wood of higher specific gravity might be advantageously introduced into the stream of raw material. Since burst factor follows the same patterns as breaking length, the graphs of figures 9 and 10 can also be figuratively translated into tear-burst comparisons.

Having so strongly implied that, of the morphological features considered, density or cell wall thickness largely determines the properties of the handsheets examined, the next immediate questions are: Why does not tracheid length influence tear factor? Why do not the tracheids of initially longer lengths result in paper fibers of longer length and therefore cause an improvement in tear strength as compared to that of paper made from shorter tracheids? The answer to these questions also influences the interpretation of the FL component of models 2.3c and 3.3c concerning burst. However, these results to be discussed now are preliminary and subject to the procedural methods used in obtaining the data.

When the average paper fiber length was regressed on cell wall thickness and tracheid length for each beating time, as given in table 8, a very consistent pattern of responses was discovered. Though for each beating time a test of the hypothesis, $\beta = 0$, was not always statistically significant, the intercept for cell wall thickness decreased markedly, and the slope gradually changed from positive at 5 minutes to essentially zero between 65 and 95 minutes and was negative from 95 minutes on. The tests of the statistical significance of these slopes were not decisive but all the patterned information given in table 8 suggest a real cause at work and our data, for each beating time, was just insufficent to show statistical significance. The uniformity of these responses can easily be seen in figures 11 and 12.

When the data were grouped by including together the data for the first three beating times for one regression and the last two times for another, and using beating time as an additional independent variable, the slope for tracheid length was positive for the first three combined times and negative for the final two combined times. In each of these, a test of the hypothesis, $\beta = 0$, was statistically significant at the 5% level. We recognize these are not strictly legitimate tests but we were trying to develop a model not to test one.

When all the data for all beating times were considered together the effect of tree tracheid length was washed out and the test of its influence was, therefore, statistically insignificant.

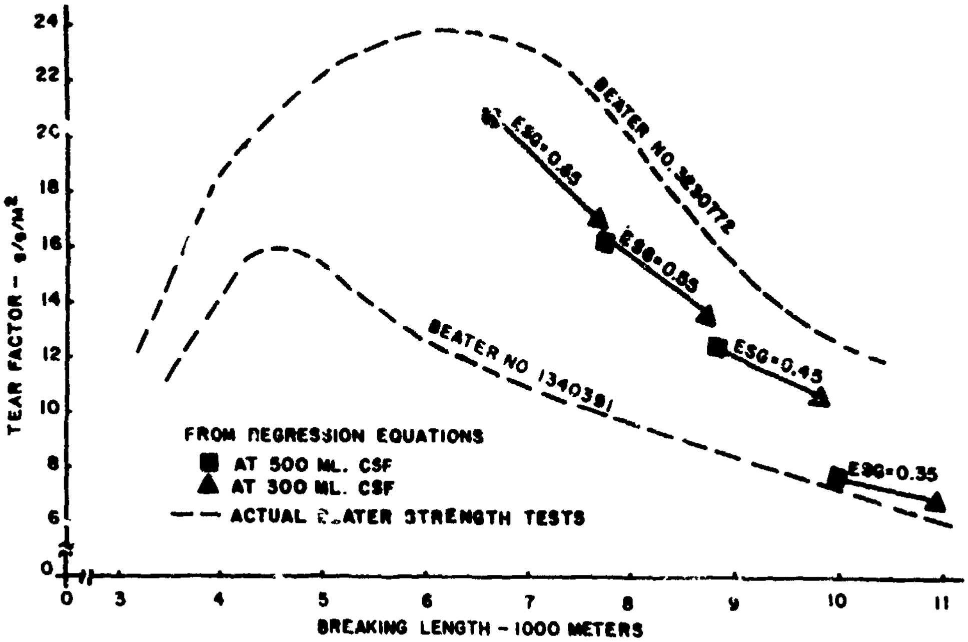

Figure 9.--The effect of the extracted specific gravity of woods on the relationship between tear and tensile strengths of pulps.

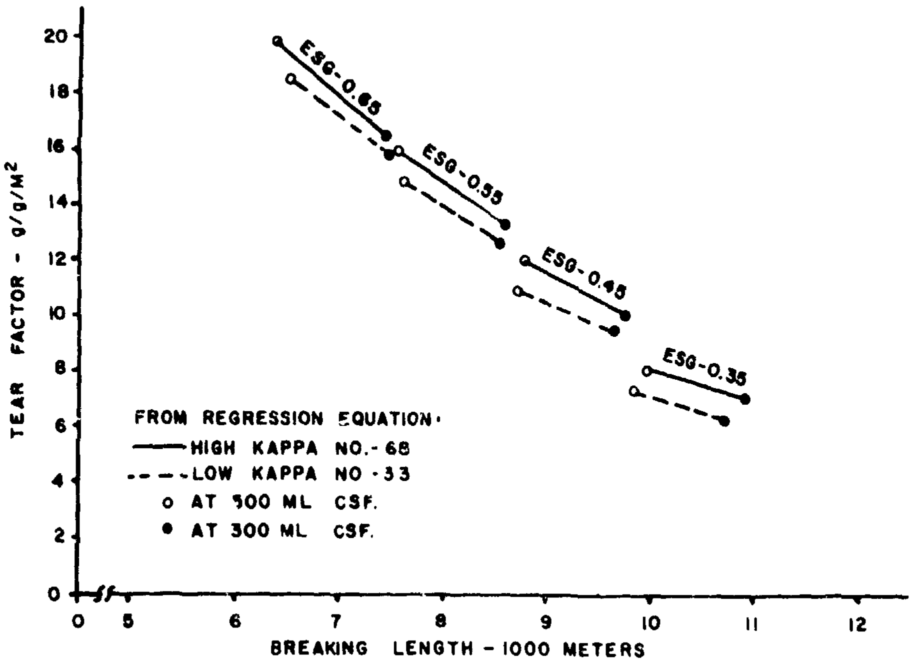

Figure 10.--The effect of extracted specific gravity of loblolly pine wood on the relationship between tear and tensile strengths of kraft pulps (based on core and outer wood).

Table 8. Regressions for average paper fiber length for each beating time involving cell wall thickness and tracheid length

Beating time	Model	d.f.	t_1	t_2	R
Min.	Mm.				
5	AFPL = 1.083 + 0.215 CW	9	2.20		0.57
20	= 0.989 + 0.221 CW	2	4.06		.74
35	= 1.609 + 0.129 CW	14	2.32		.53
65	= 1.454 + 0.114 CW	14	1.68		.41
95	= 1.500 + 0.084 CW	14	1.48		.37
125	= 1.955 + 0.015 CW	14	.20		.05
5	= 0.799 + 0.467 TTL	9	4.30		.81
20	= 0.925 + 0.431 TTL	2	3.33		.67
35	= 1.523 + 0.263 TTL	14	2.15		.50
65	= 1.813 + 0.130 TTL	14	.84		.22
95	= 2.682 - 0.119 TTL	14	.94		.24
125	= 2.880 - 0.189 TTL	14	1.26		.32
5	= -0.11 + 0.41 TTL + 0.15 CW	9	4.44	2.44	.89
20	= -0.02 + 0.32 TTL + 0.18 CW	2	3.45	4.16	.87
35	= 0.98 + 0.20 TTL + 0.10 CW	13	1.67	1.86	.64
65	= 1.26 + 0.06 TTL + 0.10 CW	13	.40	1.44	.42
95	= 2.10 - 0.19 TTL + 0.11 CW	13	1.56	1.95	.52
125	= 2.64 - 0.33 TTL + 0.05 CW	13	1.36	.50	.36

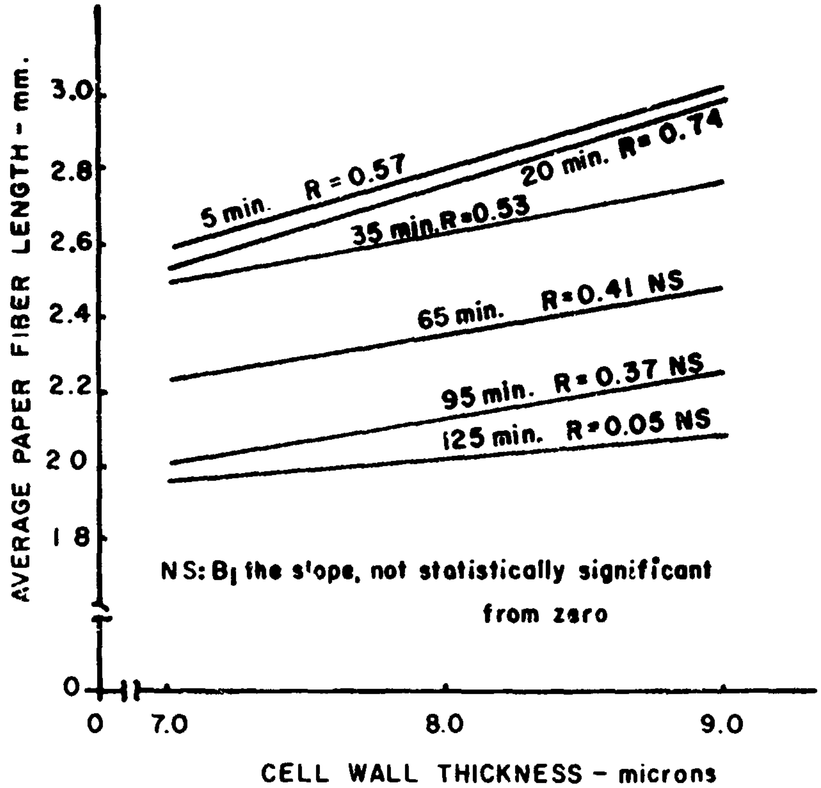

Figure 11.--The influence of wood cell wall thickness on average paper length at various beating times.

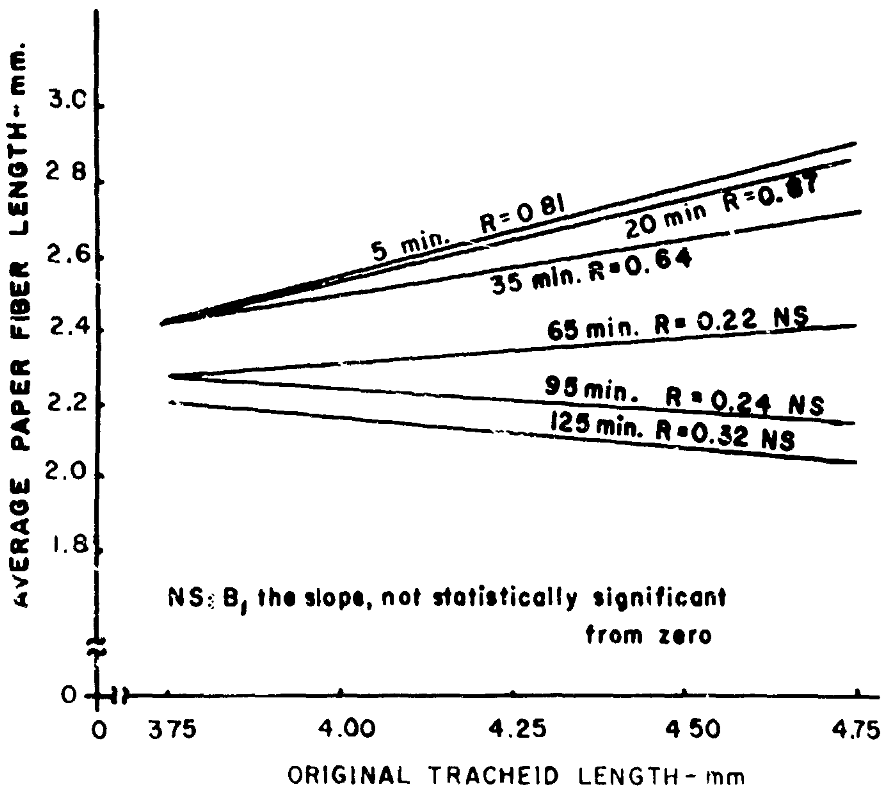

Figure 12.--The influence of tracheid length on average paper fiber length at various beating times.

The results suggest interactions between beating time and the tracheid lengths. Before attempting to make those analyses however, a test for parallelism, table 9, was set up as suggested by Williams (1959) with the result that the regression lines for each beating time (for TTL of table 8) did appear to be nonparallel. It could be argued that the regressions for 5, 20, and 35 minutes contributed most to the test, but a graph of the slopes, as in figure 13, where those for both tracheid length and cell wall thickness are shown, does indeed suggest a continuity of change in the slopes as beating time progresses.

On the basis of these implications and the evidence of figure 8, an argument can be made for formulating a model:

$$\mathrm{APFL} = b_0 + b_1\ \mathrm{BT} + b_2\ \mathrm{TTL} + b_3\ \mathrm{CW}$$

where $$b_2 = C_0 + C_1\ \mathrm{BT} + C_2\ \mathrm{BT}^2 + C_3\ \mathrm{BT}^3$$

and $$b_3 = d_0 + d_1\ \mathrm{BT}$$

Combining and simplifying:

$$\mathrm{APFL} = f_0 + f_1\ \mathrm{BT} + f_2\ \mathrm{TTL} + f_3\ \mathrm{BT} \cdot \mathrm{TTL} + f_4\ \mathrm{BT}^2 \cdot \mathrm{TTL} + f_5\ \mathrm{BT}^3 \cdot \mathrm{TTL} + f_6\ \mathrm{CW} + f_7\ \mathrm{BT} \cdot \mathrm{CW}$$

Submitting the data to this analysis and letting BT = beating time X.01 (merely to reduce the size of the numbers) resulted in:

$$\mathrm{APFL,\ mm.} = 0.88 + 1.91\ \mathrm{BT} - 0.44\ \mathrm{TTL} - 0.48\ \mathrm{BT} \cdot \mathrm{TTL} - 0.30\ \mathrm{BT}^2 \cdot \mathrm{TTL} + 0.18\ \mathrm{BT}^3 \cdot \mathrm{TTL} + 0.11\ \mathrm{CW}$$

All "t" values for the test of significance for each slope were greater than those at the 5% level for 72 degrees of freedom; the interaction BT • CW was found to be statistically insignificant in an analysis of the full model and was therefore dropped. With an R value of 0.92, this latter model accounted for 84% of the variation in the original data. The interactions of beating time (process) and original tracheid length therefore seem to be of utmost importance.

Table 9. Analysis of variance for test of parallelism for tree tracheid length regression of table 8

Source	Degrees of Freedom	Sum of Squares	M.S.	F
Single regression	1	0.067		
Difference of regression	5	.544	0.1088	4.46
Combined residual	66	1.613	.0244	
Total within groups	72	2.224		

Contribution to Different Regression

Regression Min.	Sum of Squares
5	0.239
20	.215
35	.080
65	.020
95	.016
125	.041
TOTAL	0.611
Single combined regression	.067
Difference of regression	0.544

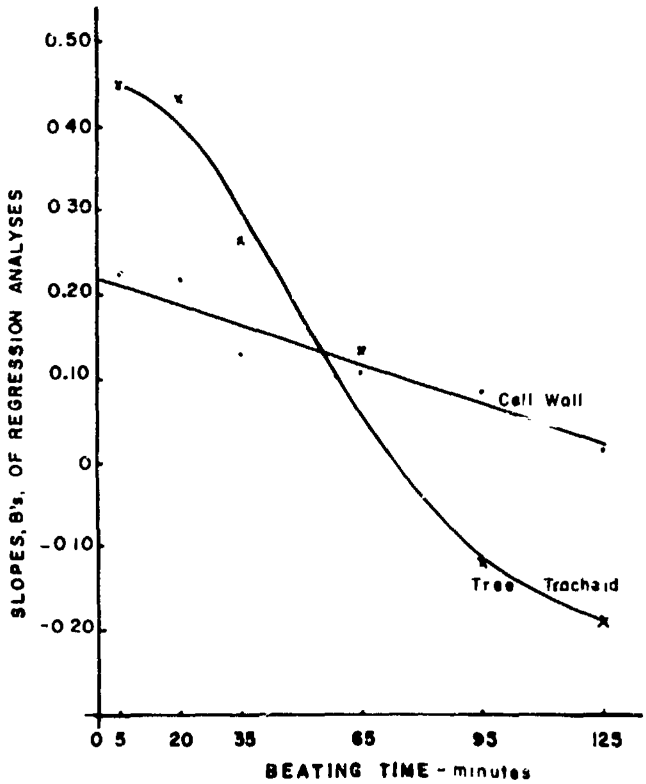

Figure 13.--A plot of the slopes of the individual regressions for average paper fiber length at each beating time.

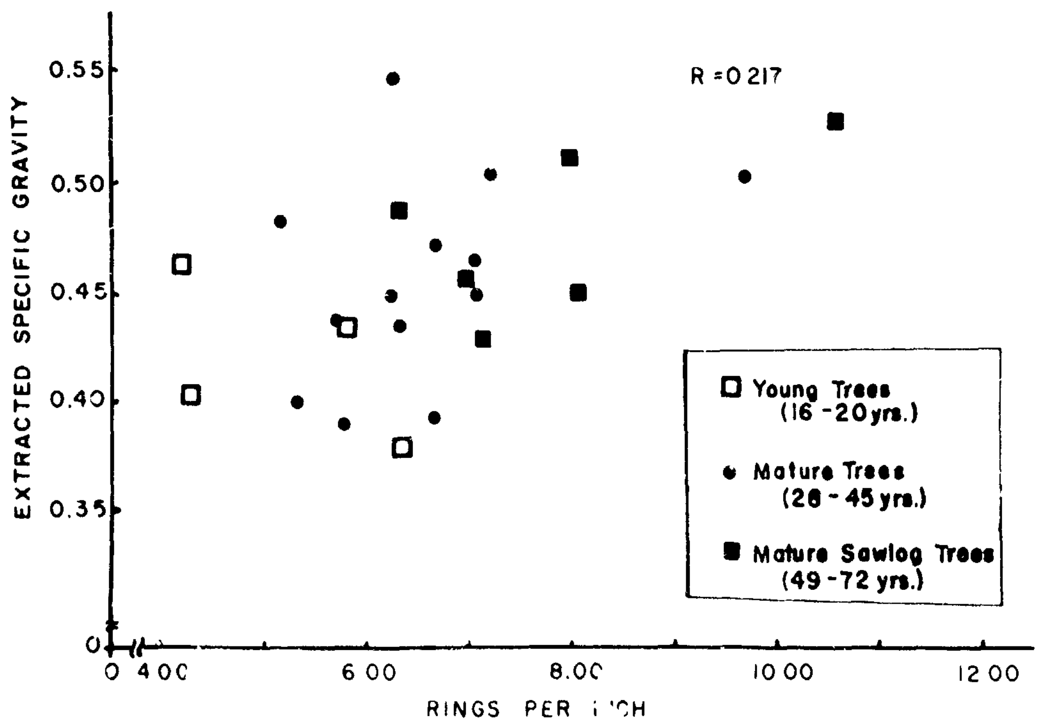

Figure 14.--The relationship of average rings per inch and extracted specific gravity for 22 loblolly pine trees.

Corte (1954) has also considered this problem thoroughly for cutting- and squeezing-refiners. He has presented means of predicting fiber lengths in paper where certain probability functions are well known for each beater. On the basis of the evidence just presented, however, it would seem reasonable to assume that Corte's probability functions would be heavily influenced by the morphology of the cells being processed.

The interesting positive coefficient for BT is not unknown to the Valley beater inasmuch as some of our other beater curves for paper fiber length definitely show such responses. Semke* confirmed that he too had seen Valley beater curves for a southern pine in which, for a period of about 20 minutes, the average fiber length increased before a decrease in length was noted. Also, as a coniferous sulphate pulp was refined, Nadelman et al. (1955) sampled the pulp and noted an increase in the fiber length during some early stages of beating. At 747 CSF, their average length was 2.74 millimeters, at 400 CSF 2.84 millimeters, and at 200 CSF 1.99 millimeters.

It therefore appears that tracheid length, if properly considered, may indeed have an effect on tear strength through its influence on paper fiber lengths. In the early stages of beating the initially longer tracheids would presumably result in longer paper fibers but at the latter stages, shorter ones. We would like to rerun these experiments and test this hypothesis--and perhaps develop some reasons for, and understanding of, what actually is occurring in our Valley beater during refining.

Having established some of the implications of the morphology of loblolly pine on papermaking of kraft pulps--and by virture of Wangaard et al. (1966) and Dinwoodie (1965), extension to all other southern pines is not an unreasonable prospect--this symposium would no doubt be interested in the correlation of some of our morphological features to the age and growth rate of our trees.

Some of the correlations among 22 of the trees for growth rate, age, specific gravity, and wood yields are given in table 10. One of our older trees was omitted from analysis because moisture content determinations were not made and therefore weight yields of wood were not available. For the data forming the basis of table 10, there are obviously many more correlations which could have been included, i.e., the correlation of rings per inch x age, which was 0.59 for these 22 trees. Of those reported, we selected those variables of greatest interest. Examined individually, most of these correlations lend themselves to ready biological explanations. For example as a tree becomes older, fewer rings per inch are usually produced but the tracheids are longer and cell walls slightly thicker. There the positive correlations for rings per inch to tracheid length and cell wall thickness follow biological expectations. Likewise, within the age span for our trees, it is not surprising that as the trees become older more pounds of wood per year and more volume of wood per year were produced. What may be unexpected is that the specific gravity of the tree does not appear to be related to these latter values. The low correlations, 0.01 and -0.02, seem to indicate the independence of these production parameters with specific gravity.

*Semke, Kirk. 1968. Personal communication, Riegel Paper Company, Riegelwood, N.C.

Table 10. Some of the linear correlations, R, among the growth properties of 22 loblolly pine trees pulped for kraft papermaking studies

Variables	- Number of Observations =	22 Whole Tree Values
Rings/in. X sp. gr.[1/] 0.51	Rings/in. X lbs./yr. 0.09	Rings/in. X cu. ft./yr. -0.07
Age X sp. gr. 0.33	Age X lbs./yr 0.64	Age X cu. ft./yr. 0.55
Unextracted[1/] sp. gr. Extracted[1/] sp. gr. 0.99	Sp. gr. X lbs./yr. 0.01	Sp. gr. X cu. ft./yr. -0.22

Variables	- Number of Observations =	52 Zone Values
Sp. gr. X % summer. 0.88	Sp. gr. X tracheid length 0.56	Sp. gr. X cell wall thick. 0.86
% summer. X rings/in. 0.67	% summer. X tracheid length 0.68	% summer. X cell wall thick. 0.95
Rings/in. X sp. gr. 0.65	Rings/in. X tracheid length 0.63	Rings/in. X cell wall thick. 0.74
Cell wall thick. X tracheid length 0.74	Cell wall thick. X rings/in. 0.63	Cell wall thick. X (tracheid length/cell diameter) 0.95
Chip moisture content X sp. gr. -0.44	Chip moisture content X tracheid length -).09	Chip moisture content X cell wall thick. -0.24

[1/]Specific gravity for this table is the Unextracted Specific Gravity: Except for U.S.G. X E.S.G., R = 0.99.

An examination of figures 14 to 16 gives an overall view of the data making up the base for these correlation values. Had the young trees been excluded from these correlation analyses, no doubt a weak negative relationship between wood production and specific gravity (shown as extracted specific gravity in these graphs) would have been noted, a relationship well established in many of our minds. Yet if you examine these data about any given growth rate, it seems that high and low specific gravity trees could be found with high rates of growth.

Again excluding the young trees, the plotted data of figures 15 and 16 still suggest that, on the average, conditions which favor rapid wood production also may lead to lower specific gravity. Fertilization studies, similar to Posey's (1965), lend credence to believing that accelerating growth does cause a decrease in cell wall thickness, for example, and hence a lower specific gravity might result. In loblolly pine, even if cell walls are thinner, if proportionately more summerwood is produced per unit volume, then the specific gravity of the wood could be higher than wood having thicker cell walls.

A multiple regression from the data of the 22 trees of specific gravity on age and cubic feet per year gave:

$$SG = 0.433 + 0.002 \text{ Age} - 0.099 \text{ ft.}^3/\text{yr.}$$

with F values of 8.09 and 6.38 respectively for a test of significance for the two slopes. From this multiple regression it would appear that at any given age, an increase in the production rate of wood would lead to a lower specific gravity; in contrast to the implications of the previously noted low simple correlations of specific gravity to production rate.

Figures 17 and 18 give the scatter of data about the regression lines for cell wall thickness and tracheid length (fiber length) when regressed on rings per inch. Both graphs follow the biological time sequence of increasing age. As the age of the tree increases, usually the rings per inch increase and likewise the tracheids are longer and, with more summerwood, thicker walled. The relationship between the plotted points and the lines indicate however that a leveling-off in thickness and length may have occurred when the rings per inch reached 12 to 18; i.e., old trees. That relationship, of course, is also well accepted.

The trees used in this study were exceptional specimens, relatively free of compression wood, knots, and pitch. Nevertheless, it seems that the important elements to consider for pulpmaking and papermaking, regardless of growth rates, are the characteristics of the individual cells. Of these morphological qualities, the thickness of the cell wall seems to be a dominant one, and certainly, the amount of summerwood influences the average cell wall thickness. As an easily determined measure of these qualities, the specific gravity is an overall parameter which seems frequently to cover adequately the impact of the morphological nature of the wood.

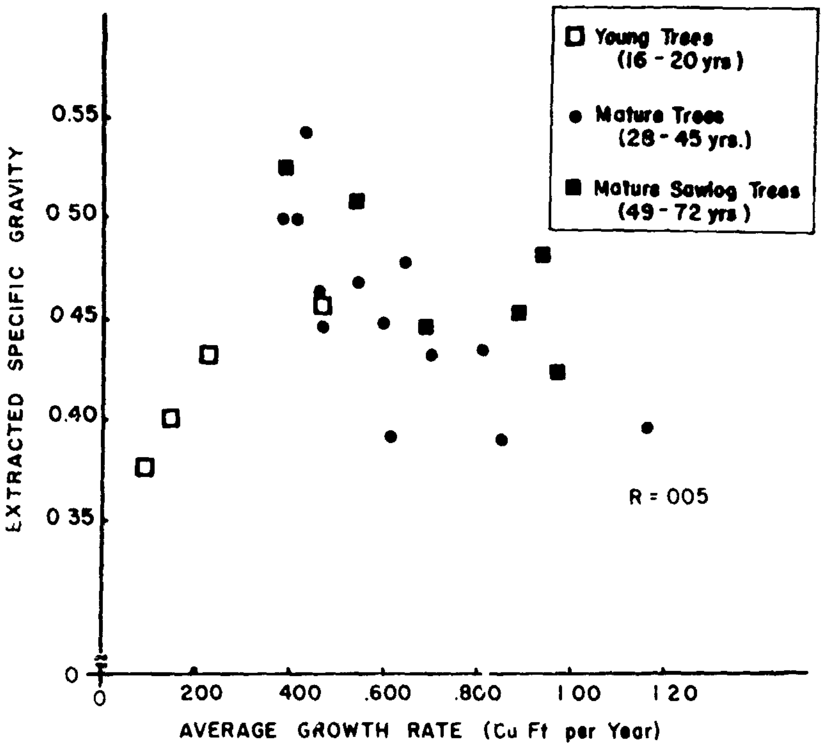

Figure 15.--The relationship of average volume growth rate and extracted specific gravity for 22 loblolly pine trees.

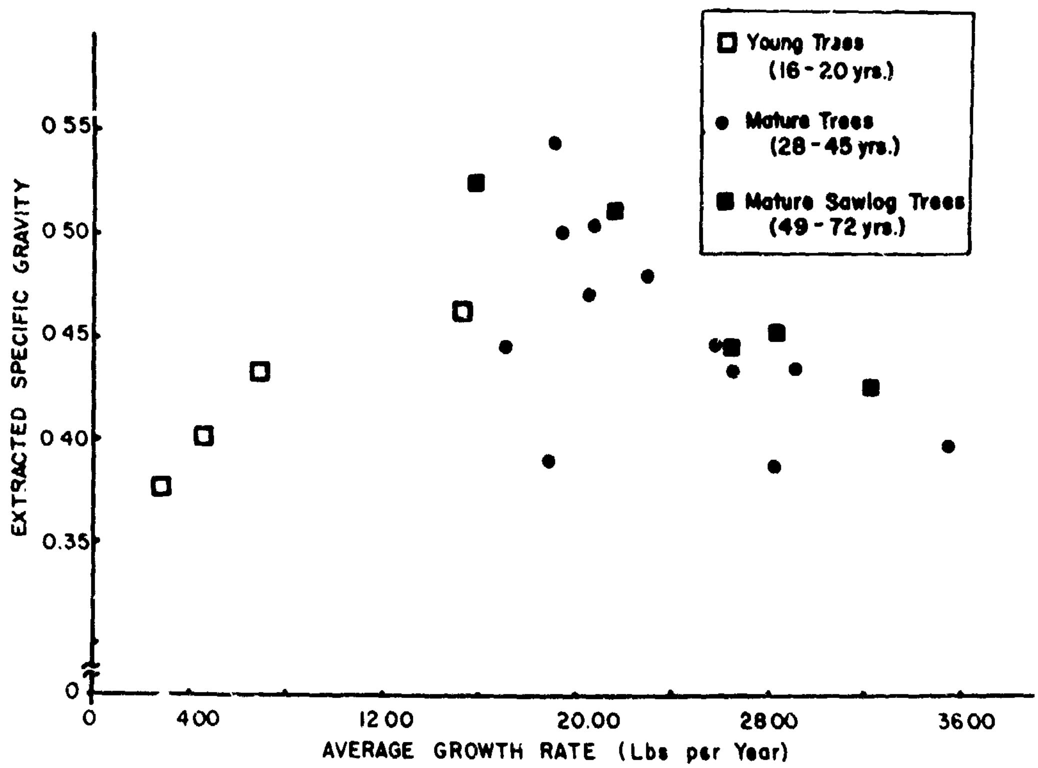

Figure 16.--The relationship of average growth rate and extracted specific gravity for 22 loblolly pine trees.

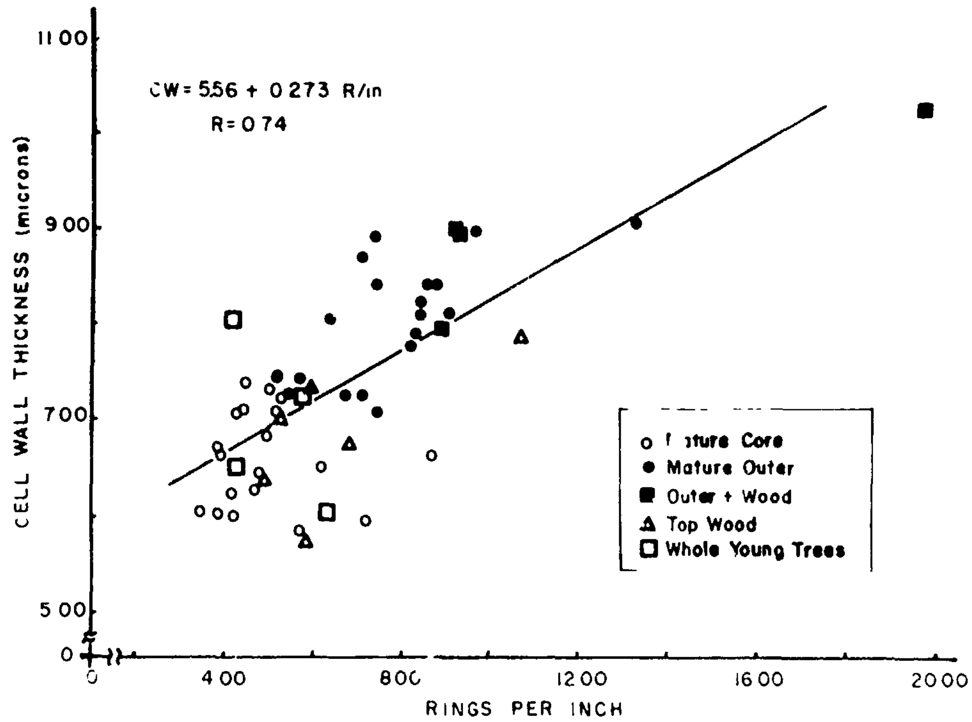

Figure 17.--The relationship of average rings per inch and cell thickness for 52 samples of wood from 23 loblolly pine trees.

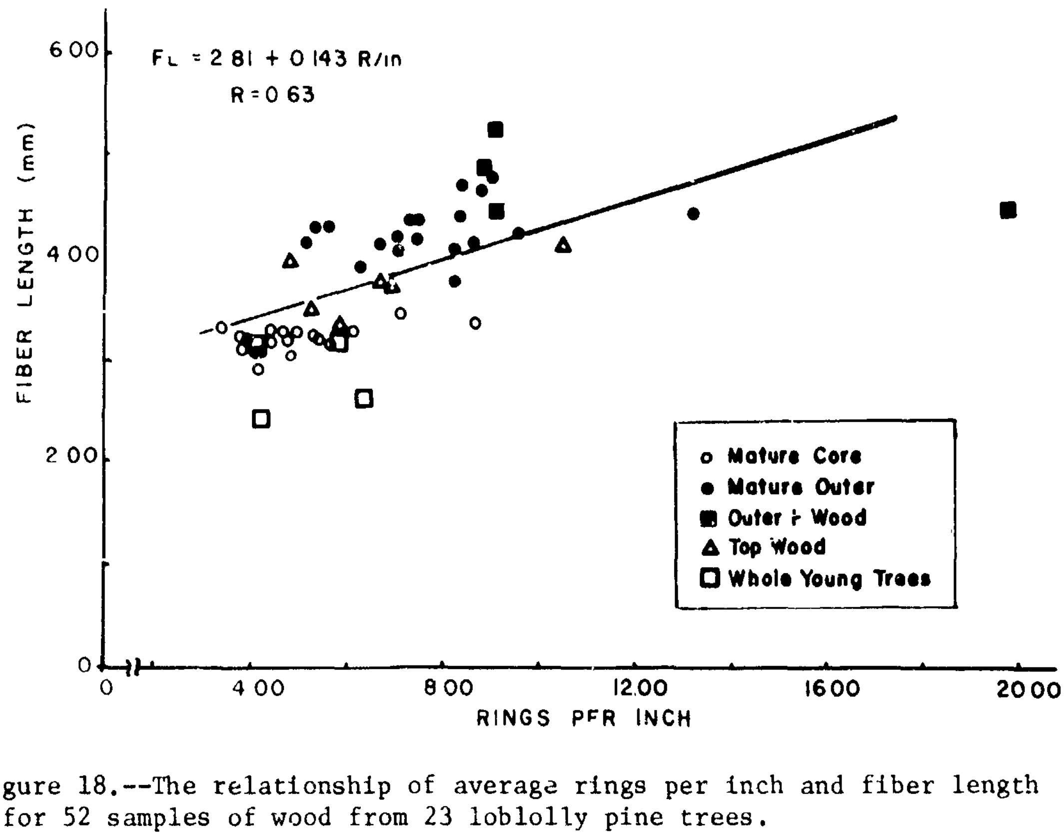

Figure 18.--The relationship of average rings per inch and fiber length for 52 samples of wood from 23 loblolly pine trees.

Implications

This study has demonstrated a relatively high correlation between certain characteristics of loblolly pine wood and the paper properties that are derived after kraft cooking followed by refining. Considering the many processing steps including chipping, blowing, screening, washing, and refining, the relatively high levels of correlation determined in this study accent the substantial influence of naturally occurring wood and fiber differences, in one tree species, upon pulp quality.

High correlations of fiber morphology properties with the total yield were not established by this study. Since the sulfate process is one involving partial solution of carbohydrates and lignin compounds of varying molecular weights in an alkaline media, chemical properties might be expected to predominate in yield relationships rather than morphological characteristics. Pulping with constant effective alkali did result in a statistically significant correlation of yields with the percent summerwood.

When the digestions were carried out to produce low-yield pulps at a constant degree of lignin purity or constant kappa number, pulping to the lower residual lignin levels insured a substantial removal of nonresistant carbohydrates across the fiber walls and associated middle lamella areas. Higher portions of the residual pulp was alpha-cellulose and since differences in alpha-cellulose content between trees are relatively small, compared to differences in other wood components, low-yield pulps from various trees would result in relatively small differences in total yields.

With the relationships developed within this investigation, a knowledge of the fiber morphological properties should aid the forest tree geneticist in developing the type of growing stock the paper industry will require in the future. It should indicate, within the framework of the trees selected for this study, that wood density variations appear more important than changes in tree fiber length. It also points out the prominence of the varying cell wall thickness on paper properties and points to the direction of using more mature wood or producing thick-walled juvenile wood if high tear strength or high bulk is desired in the end product. The use of relatively young-growth trees, with low summerwood volumes, is desired if papers of high burst and tensile strengths are preferred The particular type of loblolly pine wood sought will depend on the long-range needs of a particular company's products.

Long-range plans to substantially shift wood properties from the average values being used today may not be necessary or desirable. Being able to process a more uniform raw material would certainly be most desirable to reduce process variation and to operate more efficiently.

To the forest manager, the knowledge of the relationship between wood properties and paper properties should allow him to place emphasis on those cultural practices which will result in pulpwood better alined with the paper products being manufactured by his company. In harvesting both natural stands and reforested areas, the character of wood, as it matures, should also serve as a guide to the establishment of cutting cycles, the degree of thinning, and the density of residual stands.

Since most mills are in a position of having to accept a mixture of wood offered in their procurement area, for the short run, an inplant method of pulpwood separation or chip separation plan probably would be attractive from a practical sense. Little attention has been paid to day-to-day chip supplies other than sampling to determine moisture content and chip size. The results presented here would indicate the additional determination of wood density might be helpful to explain changes in pulp and paper strength properties during otherwise normal operation. When the wood supply is made up of regular round logs, sawmill slabs and edging and veneer cores, segregation in separate chip piles appears possible. Later reclamation for specific pulp strength properties might then be feasible. Veneer cores made up of core wood might be used to produce papers where high burst and tensile properties are desired. The chips from slabs and edgings, being principally outer wood, would be suitable where high tear bulk and rigidity properties are desirable in the final sheet.

In a mill manufacturing essentially a single grade of paper or paperboard, the segregation of chips might form the basis of differential refining. Cooks made from the different chip sources would be refined to maximize the specific strength properties desired.

If acceleration of growth, through fertilization or other means, causes a change in cell wall parameters then all of the foregoing comments would apply to the "new" wood. Obviously, the mills would need to modify their processing in order to adapt to this "new" wood.

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* * *

Gordon--There are two or three other matters that we have time for at this time. I would like to ask Professor Burkart if he would come forward for a 5-minute presentation he talked to me about before. I indicated that, if there were time at the end of today's program, he might speak about irrigation of the forest and various species with particular effluents. Mr. Burkart.

Leonard Burkart from Steven F. Austin State University

The question came up about the possible use of pulpmill effluents for irrigation. We've been doing microstudies on this matter over the last 5 or 6 years. And we have found a number of things. One, the trees themselves are quite tolerant to pulpmill effluent. We have worked with hardwoods and we've worked with some exotic hardwoods, eucalypts in particular, which seem to grow fairly well in our semiarid southwestern part of the state; we've worked with pines; we've worked with the shrubs and those plants that are of more concern to the biologists, the game manager; and this sort of thing. Most of the plants are fairly tolerant.

The big problem with pulpmill effluent is the high sodium-ion content. And this sodium-ion content, even in extremely high concentrations in parts per million, had little if any effect on these trees and shrubs and even on the flora and fauna, the micro-organism type, for our studies which ran for at least 2 years. Now beyond that, we haven't been able to conduct studies because our time has been limited.

On the other side of the coin and of greatest concern, unless you have soils that are extremely sandy, the high sodium-ion content tends to disperse the soil and plug it up. Liming has a temporary opening effect. And if you're in an area where you have high rainfall, there seems to be enough natural rain to leach out some of the sodium ions. But on the high-clay soils, and we're very wealthy with high-clay soils in our part of the country, the sodium seems to replace the other elements--particularly the microelements on the clay exchange. Before long you have little if anything but sodium. As the exchange is saturated, the sodium itself begins to leach out and get into the ground water table.

What we have found, if we separate the effluent into different categories, is that most of the sodium ion comes from the bleach plant effluent, at least so far as the kraft pulp is concerned. By separating the bleach kraft effluent from the remaining effluent and treating them separately, a large percentage has a sodium-ion content. Put it this way, most of the water from the papermill has a sodium-ion content low enough that the soils will tolerate it and the leaching effect is not deleterious.

We have done some work where we separated these effluents from different parts of the mill and, by recycling and this sort of thing, are hoping to cut down on the total sodium ion that gets into the effluent. If this is possible, it could mean many millions of gallons would be available for pulping.

Now there's one other thing to be kept in mind. A board mill in our part of the country is using a 200-acre irrigation field to dispose of its effluent. The first

problem they ran into was that everything went anaerobic because the fines tended to plug up the soil, even on the low-sodium content. Then they had a high BOD content of untreated material, and it went anaerobic.

This was in an irrigation field. We put the effluent into the forest where we had the root systems keeping the soil open and permitting more percolation, and we didn't run into that. But we're finding that high BOD actually can serve as a fertilizer for the microflora and microfauna and also for the macrofauna of the forest. It's a good possibility, but we must get rid of this high sodium-ion content before it can be practiced on most soils. The sandy soils might permit the percolation down through but the effect on the ground water table could be deleterious. We don't know.

* * *

?????--Could you define your use of the word "tolerant." Do you mean the forests accept it or is it beneficial?

Burkart--There was no difference of statistical significance between the controls where we used less water and where we used the high level. We took the extraction water, which has the highest amount of sodium ion and used it directly, and we used the acid water from chlorination directly. There was no significant difference. One was up close to a pH of 8-1/2 to 9 and one was down around the acid side. Now we had no check on the effect on wood. This was just on the seedlings that grew in pots, with the effect pretty much the same in each case. And then we had some irrigation out to check the effect on the natural forest.

?????--I have the impression that most of the technical problems had to do with growth acceleration and are beginning to be handled and understood. But what is the priority between growing a lot of fiber and growing quality fiber? I wonder if before we quit tonight if you could make some comment on that.

Sheets??--The question, as I understand it, is what effect from a business point of view does growth acceleration have on the end use of the forest? That is rather complicated because it has been pointed out before today that no one fiber characteristic is suitable for all grades of papers. Southern pine as it now exists is a very good product for making linerboard or container board. It is a terrible fiber to use for making thin papers or high-quality printing papers. And that is largely because of the summerwood content and the characteristics of the summerwood fiber.

If you are in the paper business and you are manufacturing only thin papers or only high-grade printing papers, you are not much interested in growing southern pine. When you think that there are many mills in the South who are producing pulp from the southern pine and they are planting pine almost on a crop basis today, this becomes important from a future point of view. Now if somewhere we could find a tree that has the characteristics of a northern spruce but would grow down South like the slash pine, it would be wonderful. I brought up this question 15 or 20 years ago. But when you talk to the foresters about this, they say it would be great. But, supposing you did find such a tree, would it be resistant to disease and

all of this? So there are other factors involved. I do think, as long as we are growing more trees as a crop every year, the characteristics of the fiber that come from this crop are extremely important. We need as much research work and background information as possible, it seems to me, to do the best possible job in the future years.

Shoulders, Forest Service--If I plant a crop of trees today, what assurance do I have that we will still want the same characteristics in them 25 years from now when we get ready to harvest?

Burkart--I can't give you absolute assurance. When you look at what has happened in printing papers over the last 70 years, the trend is certainly toward lighter printing papers. These are thin papers; when you're talking about the very lightweight business forms, it's important that you have fibers that will make pinhole-free papers.

Sheets??--I think there is a possibility that plastics are going to fulfill a need in thin papers and for very high-grade printing papers. But these are trends that have to be followed. If you were to ask what particular tree would have the greatest overall use, I don't claim to know that much about it, but I would still say a northern spruce. If I had to plant just one tree, it would be a northern spruce-type fiber.

Zobel--Since the question of economics was asked, I might as well tell you about some work that we've been doing with eight or 10 companies. It's rather simple. Suppose you want to rate the proper time to harvest to get the maximum return on your investment. I won't give you the exact figures because they are classified. But if you took it on volume alone it might be 15 years. If you add the yields and the wood quality that you get out of it, that ups it to around 20 to 24 years. If you add to that the size of tree and the cost of harvesting, that pushes it several years more. And if you carry it all the way through to the papermill, as we have, right down to the making of paper, that adds more years. If we judge when trees should be cut based on volume alone--and ignore the kind of wood in these trees--we are going to make some horrible economic errors. For example, with 15-year-old trees and 30-year-old trees, having an equal volume of wood, one will give you 15% more paper than the other. Yet this has been ignored pretty widely in the industry. If we don't take the wood into account in assessing our forestry operation, we're going to make some awful mistakes.

?????--Recently at a Lake States Tree Improvement Conference, one of the topics was what can genetics do for the papermaker. One of the things we came up with was to go for volume production and a uniform raw material. The papermakers indicated that if they had a uniform product, they could get proper cooking times, liquor-to-wood ratios, and things like this to optimize their cooking conditions. They could improve yield and do a lot of things this way with a large volume of wood and a uniform raw material.

Gordon--How far have we gone in answering the question that was asked?

Wahlgren--Lyle, let me raise a couple of points. Isn't this one of the purposes of the symposium? We're all motivated by one thing in the not-too-distant future--the increasing demand for wood and wood fiber products. At our present rate of growing

trees we just won't meet it. So one of the avenues open, in addition to genetics and tree improvement, is this idea of culturing techniques. The culturing technique that you apply is going to be dictated by the economic situation. From what we've talked about so far today, the situation doesn't look too bad, as far as pulp and paper is concerned, with regard to type of properties and so on of this rapidly grown material. I think we'll pursue this in greater depth tomorrow with the panel discussion.

Gordon--We'll have a wrapup then on this specific aspect tomorrow.

VOLUMES, WOOD PROPERTIES, AND FIBER DIMENSIONS

OF FAST- AND SLOW-GROWN SPRUCE PINE

by

FLOYD G. MANWILLER[1]

Abstract

In fast-grown stems of Pinus glabra Walt. tracheids averaged 0.2 mm. longer and had radial diameters 4 μm. larger than in slow-grown stems. Radial and tangential diameters of latewood were 2 μm. larger in fast- than in slow-grown stems; in earlywood, radial trachied diameter was 2 μm. larger in fast-grown stems. Specific gravity, longitudinal shrinkage, and microtensile strength did not differ with growth rate in either tissue. Fast-grown trees had more earlywood--and therefore a lower specific gravity--than slow-grown trees. Weights and volumes of stemwood, earlywood, latewood, and bark were 100% to 400% greater in fast-grown trees than in slow-grown. The gains in weights and volumes were more pronounced in 30-year-old trees than in younger or older ones.

Introduction

The southern pines are notably fast-growing species, and the efforts of geneticists and silviculturists promise to accelerate their growth rate considerably. It appears useful, then, to consider the effect that fast growth has on the properties most important in their utilization.

The literature contains substantial information derived from regional samples of several species, but there are few or no data representing an entire species. It was the purpose of the study here reported to provide such data for the commercial range of spruce pine (Pinus glabra Walt.). This species was selected because its range (fig. 1) is restricted enough to be sampled at low cost. And, though spruce pine is of commercial importance in several States, the literature contains little information on it.

Procedure

From natural stands throughout the major commercial range, 72 trees were cut in such a manner as to provide 24 statistically representative fast- and slow-grown stems in three age classes. Age classes were nominally 15, 30, and 45 years, but averaged 18.5, 30, and 46.5 years.

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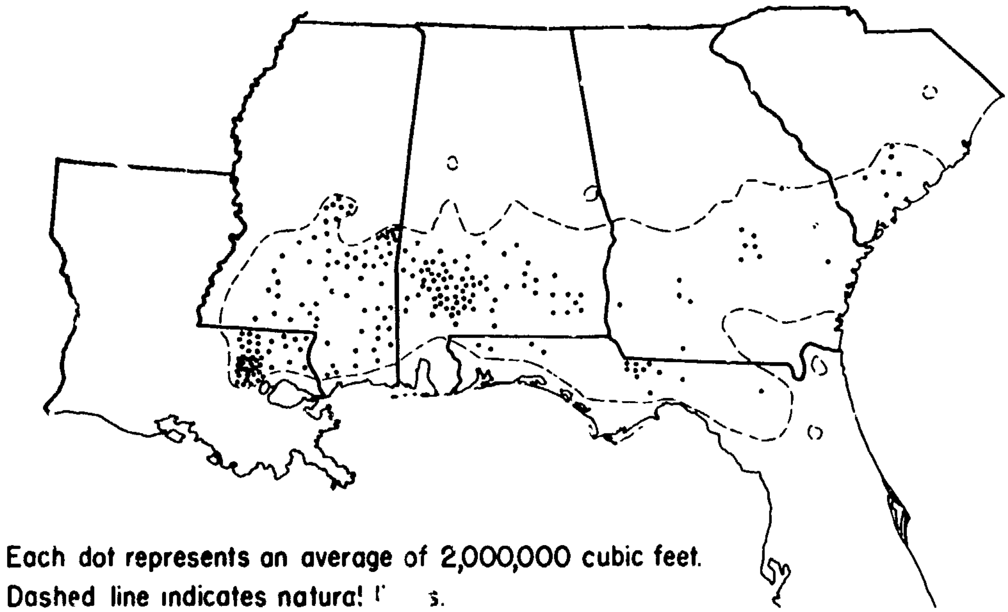

Figure 1.--Range and volumes of spruce pine (after Sternitzke and Nelson, 1970).

Within each age class half of the trees were slow grown (more than 6 rings per inch) and half were fast grown (less than 6 rings per inch). Six trees, one of each age and growth rate category were cut at each of 12 locations (fig. 2). Growth rate and age were determined at butt height of 0.75 foot, and all trees had at least one 8-foot length between this point and a 4-inch top outside bark.

To obtain stem averages for fiber dimensions the wood was sampled in proportion to its occurrence in the stem. The weighting, by volume, was accomplished by removing two opposed 30° pie-shaped wedges at 8-foot intervals up the stem. The wedges, measuring 1 inch along the grain, were chipped and the chips combined. After thorough mixing, a subsample was macerated with equal parts of glacial acetic acid and 6% hydrogen peroxide. Lengths of 150 fibers from each tree were measured with an ampliscope. Transverse dimensions were determined on 100 macerated fibers with a microscope equipped with a micrometer eyepiece. Mean fibril angle of the S_2 layer was measured by polarization; in this method (Preston, 1952) macerated fibers are glued to a slide and sliced longitudinally, and the major extinction position is determined for the single wall remaining.

Earlywood and latewood samples were obtained from nine points within each stem, three at each of three heights (butt, 4-in. top, and approximately halfway between) for a total of 1,296 sampling points. At each height an annual ring was selected at one-sixth, three-sixths, and five-sixths of the count from the pith to bark. Earlywood and latewood portions of the ring at each sampling point were excised and macerated. Fiber length and fibril angle were measured as previously described on 20 fibers of each tissue type at each sampling point.

Also, at each sampling point transverse fiber dimensions were measured with a dual-linear micrometer and specific gravity was calculated (Smith, 1965). Samples were water-swollen when measured. Dimension averages were obtained by making four traverses in the radial direction, with earlywood and latewood tallied separately. In the tangential direction four passes of 50 cells each were made within each tissue type, with only diameter measured.

Weights and volumes of wood and bark were derived from measurements at 8-foot intervals up the stem. Stumpwood was excluded. For determination of volumes, each 8-foot log was considered to be a truncated cone. The radius at each end of a log was the mean of eight radii. Mean bark thickness was derived from a measurement at each of the eight radii. For both wood and bark, log volumes were added to obtain stem volume.

Earlywood and latewood volumes were computed by first determining the percent of latewood at one radius on each end of the log. Latewood was computed by an equation (Miller and Malac, 1956) which recognizes that a latewood band near the bark contributes more to area than does one of equal width near the pith:

$$\text{Percent of latewood} = \frac{2\Sigma(r_o x) - \Sigma x^2}{R^2}(100)$$

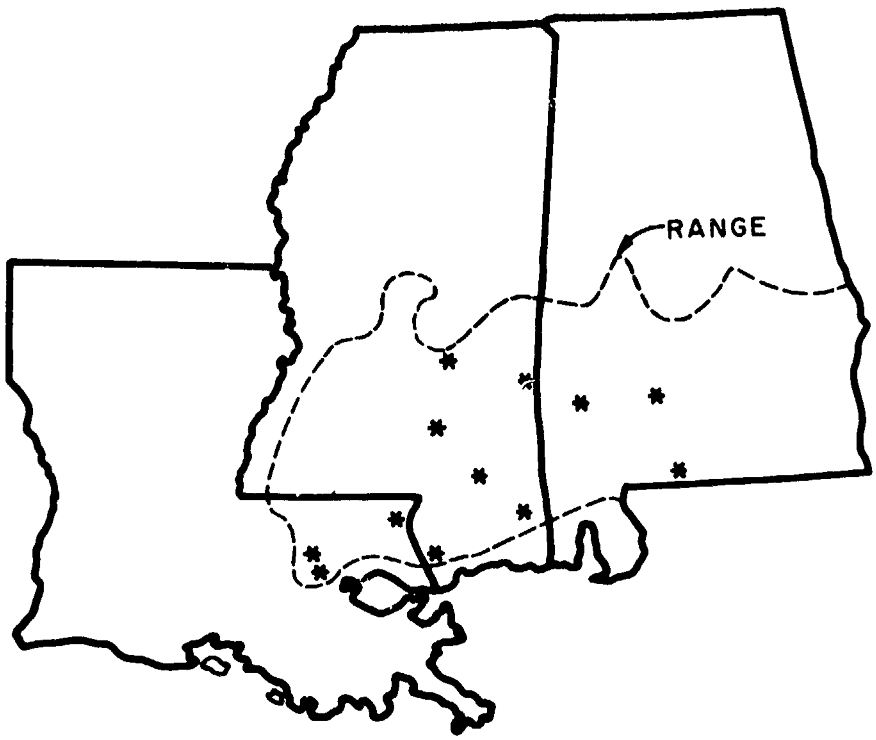

Figure 2.--Sample locations.

where

r_o = distance from pith to end of the annual ring

x = width of ring's latewood

R = wedge radius

The percentages for the two log ends were averaged and multiplied by log wood volume to arrive at log latewood volume. Earlywood volume was computed as the difference between stemwood and latewood volumes.

Total ovendry stemwood weight was computed from stem volume and stem specific gravity (green volume and ovendry weight). The latter was obtained from 30° wedges, 1/2-inch thick, taken at the 8-foot intervals.

Bark specific gravity (green volume and ovendry weight) was measured on the two 30° wedges used for fiber determinations.

A tree average specific gravity was not available for converting earlywood and latewood volumes to weights. However, earlywood specific gravities calculated from the dual-linear micrometer measurements were found to be relatively uniform. They were highest at the butt and highest near the pith at all levels, but there were no differences among age classes or between growth rates. Therefore, the average of all 648 earlywood samples (0.376, based on green volume and ovendry weight) was used to convert earlywood volume to weight. Latewood weight was taken to be the difference between stem weight and that of earlywood.

Microtensile strength specimens were obtained from the annual ring selected at each of the positions within a stem. Radial wafers approximately 300 µm. thick were cut from saturated blocks with a power microtome. Earlywood and latewood specimens were cut from each wafer with a pair of microtome knives spaced to yield strips 100 to 500 µm. in width. A pair of notecard tabs was glued with epoxy to each end of the specimens; gage length was 1/2 inch. The specimens were then pulled to failure with a universal testing machine.

Longitudinal shrinkage specimens were also obtained from the wafers cut with the microtome. The radial dimension varied with width of the tissue. Swollen and ovendry lengths were measured to 0.1 µm. on a dual-linear micrometer. Three specimens were measured at each sampling point.

Results and Discussion

As table 1 shows, tracheids of slow-grown trees (av. 9.0 rings per in.) averaged 3.5 mm. in length while those of fast-grown trees (av. 4.9 rings) averaged 3.7 mm. Tracheid radial diameter averaged 41.9 µm. in slow-grown trees and 45.9 µm. in fast-grown. There were no significant differences (0.05 level) between growth rates for wall thickness, lumen diameter, or fibril angle.

When unweighted earlywood and latewood tissues were considered separately, tracheids of fast-grown wood again were larger in diameter. Those of latewood were larger in both radial and tangential dimensions--25.3 µm. vs. 23.3 µm. and 29.4 µm. vs. 27.5 µm.,

Table 1.--Fiber dimensions in whole wood, earlywood, and latewood of 72 fast- and slow-grown spruce pines[1]

Property and growth rate	Whole wood[2]	Earlywood[3]	Latewood[3]
Tracheid length, mm.	*	NS	NS
Slow	3.5	3.1	3.5
Fast	3.7	3.2	3.6
Radial diameter, μm.	*	*	*
Slow	41.9	36.4	23.3
Fast	45.9	38.4	25.3
Tangential wall thickness, μm.	NS	NS	NS
Slow	5.7	3.4	5.8
Fast	5.9	3.6	6.0
Lumen radial diameter, μm.	NS	*	*
Slow	30.5	29.5	11.7
Fast	34.1	31.2	13.2
Tangential diameter, μm.		NS	*
Slow	--	29.2	27.5
Fast	--	30.8	29.4
Fibril angle, degrees	NS	*	NS
Slow	35.1	37.5	34.2
Fast	36.6	39.0	35.2

[1] Values tabulated below an asterisk differed significantly at the 0.05 level; values that did not differ statistically are labeled NS.

[2] All measurements made on macerated fibers sampled with intensity proportionate to volume in stem. Sample comprised of wedges removed at 8-ft. intervals along stem to a 4-in. top.

[3] Sampling was at 9 locations within each stem; i.e., at 3 radial positions at each of 3 heights. Fiber length and fibril angle measured on macerated fibers; transverse dimensions measured on surfaces of water-swollen blocks.

respectively. In earlywood, only the radial diameter was significantly larger (38.4 µm. in fast-grown wood and 36.4 µm. in slow-grown). Wall thickness and fiber length did not differ with growth rate in either tissue. Fibril angle differed only in earlywood, where it averaged 1.5° greater in tracheids from fast-grown trees.

Stem earlywood volume was 69.2% in slow-grown trees and 74.6% in fast-grown. In both tissue types, the number of cells in a radial file was negatively correlated with rings per inch. Earlywood tracheids averaged 75.5 per ring in slow-grown trees and 116.5 in fast-grown; in latewood the numbers were 35.2 and 47.2. Earlywood cell count averaged 63.7% of total cell count in slow-grown trees and 68.2% in fast-grown.

As determined from the nine sampling points in each tree, annual ring width averaged 0.14 inch in slow-grown trees and 0.22 inch in fast-grown.

Though fast-grown tracheids in both tissues were larger in diameter and displayed no change in wall thickness, there was no significant reduction in specific gravity. For earlywood, extractive-free specific gravity averaged 0.379 in slow-grown trees and 0.373 in fast-grown. In latewood, the values were 0.699 and 0.683.

Stem specific gravity strongly reflects the large proportion of earlywood in fast-grown trees. Extractive-free specific gravity averaged 0.432 in slow-grown trees but only 0.395 in fast-grown. For unextracted wood the values were 0.442 and 0.405.

Stem bark of slow-grown trees averaged 0.19 inch in thickness and had a specific gravity of 0.387. Fast-grown trees had 0.22-inch-thick bark and specific gravity of 0.361.

Longitudinal shrinkage did not differ between growth rates. Shrinkage from green to ovendry condition averaged 0.50% for slow-grown earlywood and 0.49% for fast-grown. In latewood, it averaged 0.27% and 0.26%.

Growth rate had no effect when specimens were tested in tension. Maximum stress in earlywood averaged 8,490 p.s.i. in slow-grown wood and 7,980 p.s.i. in fast-grown; modulus of elasticity averaged 519,380 p.s.i. and 492,510 p.s.i. In latewood, maximum stress averaged 19,020 p.s.i. in slow-grown wood and 19,840 p.s.i. in fast-grown, while modulus of elasticity averaged 1,102,500 p.s.i. and 1,105,360 p.s.i. These strength values are considerably lower than those typically obtained from ASTM standard specimens, but other researchers (Salamon 1966; Biblis 1969) have obtained similar results. At least part of the difference is caused by cell wall deformation induced during microtomy.

Green volumes and ovendry weights of wood and bark are presented in table 2. In the 15-year age class, slow-grown and fast-grown stems do not differ at the 0.05 level of significance. For the 30- and 45-year age classes, however, the increased yield from rapidly grown trees is dramatic. Thirty-year-old fast-grown trees contained as much wood as the older slow-grown trees, although averaging 20 years younger.

Table 2.--Tree-average green volumes and ovendry weights of merchantable stem portions from 72 fast- and slow-grown spruce pines[1]

Age class (years) and growth rate	Average age	Average growth rate	Average d.b.h.	Average length of merchantable stem	Green volume: Whole wood	Green volume: Bark	Green volume: EW	Green volume: LW	Ovendry weight: Whole wood	Ovendry weight: Bark	Ovendry weight: EW	Ovendry weight: LW
	Yr.	Rings per in.	In.	Ft.	Cu. ft.				Lb.			
15												
Slow	19.4	8.3	4.9	13.5	1.4	0.2	1.0	0.4	38.7	5.4	[illegible]3.0	15.7
Fast	17.7	4.6	8.0	31.5	7.0	.8	5.3	1.7	172.3	18.6	124.2	48.1
30												
Slow	30.[illegible]	9.2	6.7	32.0	5.5	.7	3.6	1.9	155.3	17.5	86.2	69.1
Fast	29.2	4.8	12.1	56.5	23.1	2.6	16.9	6.2	581.3	61.1	397.8	183.5
45												
Slow	49.0	9.6	10.6	53.0	18.6	2.1	13.1	5.5	481.5	50.5	308.1	173.4
Fast	44.3	5.3	16.7	72.0	53.9	4.8	39.7	14.2	1,338.5	114.4	931.0	407.5

[1] Merchantable stem to a 4-in. (outside bark) top with butt height of 0.75 ft.

Earlywood content consistently increased proportionately more in volume and weight than did other stem components. In the 30-year age class, the slow-grown trees contained 3.6 cubic feet of earlywood, while the fast-grown trees had 16.9 cubic feet--a gain of 369%. Corresponding increases were 226% in latewood, and 320% in whole wood volume.

Gains were smaller in the 45-year age class, but the fast-grown trees in this group contained double the volume and weight of 30-year-old, fast-grown trees. The least increase in the 45-year class was in amount of bark: 50.5 pounds in slow-grown trees and 114 pounds in fast-grown--a gain of 126%.

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* * *

Maeglin, FPL--Did you have uniform growth rate on these samples?

Manwiller--We tried very hard to get a uniform growth rate; within the biological variation you get, it was pretty uniform.

Echols, Berkeley--I was interested in your sampling technique. What criteria did you use for selecting your fast- and slow-grown samples, were they in plantations or natural stands?

Manwiller--All natural stands.

Echols--How do you account for the fast growth in some and slow growth in others? Is this competition and just happened that way, or what?

Manwiller--It just happened this way. They don't plant spruce pine down there, it comes in naturally when it's opened up. Actually I think in that part of the South you will find these increasing somewhat in total volume. We went into these natural stands and just hunted until we found either fast- or slow-grown trees.

Kellogg, Canadian FPL--I was amazed that you were able to detect a difference in fibril angle of 1-1/2°. This must be an extremely uniform material.

Manwiller--We had a lot of samples. There were 1,296 sampling points plus we measured 150 fibers at each sampling point. There was a fair amount of variability, I'll guarantee that.

WOOD PROPERTIES OF YOUNG LOBLOLLY AND SLASH PINES[1]

by

B. J. ZOBEL[2]

R. C. KELLISON[3]

D. G. KIRK[4]

Abstract

The trend of southern forestry is to decrease age of harvest for several reasons. This trend toward greater use of young wood and topwood so alters the type of wood received by the processing plant that an understanding of the differences between young wood and mature wood must be mastered if plant operation is to be efficient.

Juvenile or young wood is located within a core of about 10 annual rings within the merchantable bole of the tree. It is characterized by having lower wood specific gravity, higher moisture content, shorter tracheids, greater lumen diameter, and thinner cell walls than mature wood. It has pulp and paper properties that are lower in cellulose yields, greater in burst and fold, and lower in tearing strength and opacity than mature wood. It is more costly to process, and tall oil and turpentine yields are less than those obtained from mature wood. Topwood of merchantable bolts has properties similar to juvenile wood except that the tracheids are considerably longer and that it contains more knots and associated compression wood than does wood from young trees.

Reducing the amount of juvenile wood in a tree has prompted such suggestions as planting at close spacing with frequent thinnings at older ages. This is biologically and economically impractical because juvenile wood is related to number of rings from the pith, not to width of ring or distance from pith. Breeding for juvenile wood that has properties more similar to mature wood is a distinct possibility, as shown by a number of tests.

The wood-using industry must become cognizant of the effects of juvenile wood. The unique characteristics of the wood will have an effect on rotation age of the forest, and they will affect the yield and quality of the product and the efficiency of the processing plant utilizing the wood. To ignore any or all of the characteristics will favor the competitor who has taken them into consideration.

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Introduction--The Supply

The trend of pine forestry in the Southeast is toward shorter rotations. The causes for this trend are (1) financial pressures to obtain rapid returns on the investment; (2) forced harvest of young plantations to maintain a continuing supply of cellulose for mills where wood shortages are experienced for various reasons; (3) rapid liquidation of soil bank plantations and thinning young, overdense plantations; and (4) the interest in using juvenile pine wood for special products because of its unique characteristics.

Perhaps the largest present source of juvenile wood is from thinnings of young plantations. Many millions of acres were planted to pine by the soil bank, TVA, and other organizations at close spacings, sometimes as close as 3 by 3 feet but usually 5 by 5 feet to 6 by 6 feet. With the growth rate extant in the Southeast, these plantations are now badly in need of silvicultural treatment, which has resulted in thinning on a large scale, often using special harvesting machinery. Because of this, young wood makes up an increasing proportion of the total wood supply each year.

Another considerable source of young wood is from tops of large trees which have been utilized for plywood or sawtimber. Despite its greater percentage of knots and compression wood, topwood essentially has juvenile fiber characteristics. More complete timber utilization, particularly by the pulpwood and chip-n-saw lumber operations, will result in an increasing volume of small-diameter tops for pulpwood usage. Numerous organizations are now using tops below the classical 4-inch "merchantable" diameter limit and the trend is gaining momentum. Although not large in total volume, a considerable amount of juvenile wood from plywood cores is used locally.

On a global scale, perhaps the greatest usage of young wood will be from the extensive tropical and subtropical conifer plantations. These grow so rapidly that often a size criterion for harvesting results in utilization of trees that are essentially all juvenile wood. This source of young wood will expand rapidly as millions of acres of recently established plantations reach a merchantable size. The often cited benefit of very rapid growth and young harvest age in tropical areas can be negated by rejection of the wood produced. Many thousands of acres of plantations that are merchantable already are not being utilized. For whatever the reason, it is clear that young wood is going to be used in increasing amounts, and we need to know its yield, qualities, and product characteristics if major problems in forestry and product acceptability are to be avoided. This paper reports on wood qualities and pulping characteristics of young southern pine from "just merchantable" to trees 15 years of age as well as for small-diameter wood from tops of young and old trees. A short treatment on alteration of wood properties and the effects that intensive forest management will have on wood qualities is also given.

Prevalence of Juvenile Wood

The presence of juvenile wood within a tree is recognized and its importance generally accepted (Dadswell, 1957; Paul, 1957; Zobel et al., 1959; Zobel, 1961; Rendle, 1960; Hallock, 1968). Many authors (Larson, 1962; Cooper, 1960; Paul, 1960; to name a few) feel that juvenile wood is essentially "crown formed" and is the resultant of physiological factors associated with actively growing meristems. However, Zobel (1961) pointed out that juvenile wood is not produced for a longer time in southern pine trees with persistent live crowns than in those that have lost their lower limbs by natural pruning. Others such as Paul (1960) proposed that fast growth is essential for juvenile wood formation. This concept is not generally accepted because juvenile wood is related to number of growth rings from the pith, not to width of ring or distance from the pith (Rendle, 1959). The most logical explanation for formation of this wood is that it is related to physiological aging of the cambium. We find for loblolly pine that the period of juvenile wood production is approximately seven rings from the pith; Hallock (1968) reports 6 years for basal bolts, five rings for the upper bolts. For operational purposes and ease of sampling, juvenile wood in loblolly pine is often defined as the first 10 rings from the pith. It is obvious that the juvenile period lasts longer for some characteristics than for others. For example, Rendle (1959) feels that juvenility for specific gravity lasts fewer years than it does for tracheid length.

The percentage juvenile wood varies greatly among stands, depending on their age and method of measurement. For example, 47% of the volume of an 18-year-old stand in North Carolina was juvenile, based on visual separation (7 rings from the pith) whereas a 15-year-old stand in South Carolina contained 76% by weight and 85% by volume juvenile wood when 10 rings from the pith was used as the criterion of juvenility. In stands younger than about 10 years, essentially all the wood is juvenile.

Controlling Juvenile Wood

The possiblity of controlling the percentage of juvenile wood is often raised. Suggestions such as those of Paul (1960) to obtain slow growth by planting at close spacings with frequent thinnings at older ages are neither economically feasible nor biologically useful; it is ring age, not ring width, that causes wood to be formed with juvenile characteristics. Breeding for a smaller juvenile core as suggested by Rendle (1959) and Schmidt and Smith (1961) holds some promise; we noticed years ago that an occasional tree had juvenile wood with specific gravities as high as 0.60 and did not have the typical change from pith to bark. To test for the inheritance of such high-gravity juvenile wood, we sampled 800 trees in one study.[5] Forty trees, each having relatively high- and relatively low-gravity wood with small changes from pith to bark were located, and seed collected from them was used to establish progeny tests. After 5 years in the field the progeny from parents with high-gravity juvenile wood (0.492) had a tree specific gravity of 0.339 while those from the low-gravity parents (0.400) had a specific gravity

[5] In cooperation with International Paper Company, Georgetown, S.C., as part of the North Carolina State-Industry Tree Improvement Cooperative.

of 0.316. This difference among progenies from high- and low-density parents appears to be increasing with age and will certainly be larger than the 1.5 p.c.f. (pounds per cubic foot) evident at age 5.

In a study of progeny from slash pine seed orchards of Union Camp Corporation in Georgia, the 3-year-old family with the highest specific gravity (0.411) produced wood that weighed 4.4 p.c.f. more than the low-gravity family (0.346). This large difference among the 50 families represented, combined with the relatively good heritability of specific gravity, bodes well for the production of strains of trees with high or low juvenile wood specific gravity, as the need indicates.

In their comprehensive study of the effect of wood on pulp properties, Ellwood et al. (1969) state, "Topwood produced the lowest yield, then juvenile wood, then mature wood. Interestingly, some few juvenile wood fractions produced higher yields than some mature woods of the same or higher summerwood content. This indicates the possibility of genetic selection for relatively high-yield juvenile wood."

Characteristics of Young Trees

In the southern pines, juvenile wood generally has the following characteristics (covered by the previously cited authors and a host of others such as Meylan, 1968; Gilmore and Pearson, 1969):

a. Low specific gravity, with short, thin-walled cells resulting in low pulp yields and weak solid wood products. Pulp yields may be 10% to 15% below those from older wood and the paper produced has qualities that differ from paper from normal wood (Zobel et al., 1971).

b. Low cellulose yields, high hemicellulose yields (Zobel et al., 1966; Gladstone et al., 1970). Holocellulose yields are about 3% less, and alpha-cellulose about 7% less in juvenile wood than in mature wood.

c. High percentage compression wood resulting in poorer strength, difficult bleaching, and high lignin content.

d. Large fibril angle with high longitudinal shrinkage, making solid wood products so unstable that there has been discrimination against the use of southern pine lumber. The low strength properties of sawn products from juvenile wood can be magnified when mass manufacturing methods such as gang saws are employed.

e. Greater spiral grain that also makes for instability of sawn products.

Similar juvenile characteristics of wood near the tree center have been reported for other conifers such as Pinus caribaea in Australia (Schmidt and Smith, 1961) and for Douglas-fir (Wellwood and Smith, 1962). However, patterns of development may greatly differ among species; for example, there is a high-gravity zone near the pith in Sitka spruce, which drops for about 10 growth rings followed by the regular juvenile pattern (Wood and Bryan, 1960).

Specific Gravity--Whole Trees

Because of the differing gravities related to geographic source, no blanket statement can be made about the weighted wood density of the merchantable volume of a tree that will always be correct; however, in general, whole tree values[6] of 10-year-old loblolly pine are about 25 p.c.f. (dry wood) compared to 31 p.c.f. for 30-year-old trees.

Members of the North Carolina State Cooperative have determined whole tree values on several thousand young trees; results have been summarized in table 1. The increase in specific gravity with age is significant. For ease of comparison, whole tree values for 25-year-old loblolly pine from the same general area have been shown; note the decreasing difference in wood density as ages approach 25.

It is essential to know the change in specific gravity with stand age if realistic decisions on harvesting age or wood procurement are to be made. Two progeny plantations thinned at 7.5 years and again at 11 years of age will illustrate this. The change in specific gravity was considerable, amounting to 2.8 p.c.f. for one plantation, 2.3 p.c.f. for the other (table 2). Such changes markedly affect pulp yield per unit volume; an average cord will have a dry fiber weight of about 290 pounds more at 11 years than it did at 7.5 years, based upon specific gravity and content of solid wood per cord. In addition, paper quality will be affected, primarily due to thinner cell walls but also because of shorter tracheids, higher hemicellulose content, and greater lignin percentage in the younger trees.

Slash pine shows a similar pattern of change of gravity with age as does loblolly pine. Note the large change between the 11-year and 18-year age group and the small change between the 18-year and 31-year age group for slash pine from the Gulf Coast (table 3). Results from another study of slash showed the same trend in south Georgia (table 4).

A large number of trees were harvested from plantations in the Piedmont of South Carolina. Shown in table 5 are portions of the values for the young age classes calculated from the regression equation. Data for two older age classes were included for comparison.

Specific Gravity--Top Bolts and Unmerchantable Tops

In the South it is standard to utilize the tree stem to a 4-inch top. Some industries are attempting closer utilization, to a 2- or even 1-inch diameter. The question immediately raised relates to the wood properties of such small-diameter material and the qualities for pulp and paper from such wood.

Several investigations of topwood have shown that, aside from difficulties of harvesting and handling the small, limby, and often crooked bolts, wood from

[6] Merchantable volume is usually limited to a 4-inch-diameter top.

Table 1.--Wood weight of young loblolly pine aged 3 to 15 years, compared to 25-year-old trees. Values are all weighted tree values[1]

Age	Number of trees sampled	Specific gravity	Density
			P.c.f.
YOUNG STANDS			
3.0	1,177	0.35	21.9
5.0	2,175	.36	22.5
7.5	1,447	.38	24.0
10.0	927	.39	24.5
11.0	710	.40	25.0
14.0	30	.42	26.2
15.0	207	.42	26.2
25-YEAR-OLD STANDS			
25.0	--	.44	27.5

[1] To a 4-in. top diameter.

Table 2.--Specific gravity changes from 7.5 to 11 years of age within 2 plantations

Plantation	Specific gravity, 1966	Specific gravity, 1971	Increase in 5.5 years
			P.c.f.
Excellent site[1] (South Carolina Coastal Plain)	0.39	0.43	2.8
Good site[2] (South Carolina Coastal Plain)	.39	.42	2.3

[1] From a progeny test of Westvaco Corporation, Georgetown, S.C. Based on 320 trees in 1966, 128 trees in 1971 from 8 families.

[2] From a progeny test of International Paper Company, Georgetown, S.C. Based on 640 trees in 1966, 256 trees in 1971 from 16 families.

Table 3.--Specific gravity of slash pine from different aged stands in the Gulf Coast[1]

Average age	Weighted total tree values: Specific gravity	Weighted total tree values: Density
		P.c.f.
11	0.414	25.7
18	.471	29.4
31	.505	31.5

[1]From a study by Container Corporation, Brewton, Ala. (Adapted after Zobel et al., 1971.)

Table 4.--Specific gravity of slash pine 12 and 17 years of age and the wood formed during the interim[1]

	Whole tree, 12-year-old	Wood formed during 12- to 17-year period	Whole tree, 17-year-old
Specific gravity	0.42	0.49	0.45
Density (p.c.f.)	26.2	30.6	28.1

[1]From a study by International Paper Company, Bainbridge, Ga. (Adapted from Collicott et al., 1968.)

Table 5.--Dry wood weight table for young loblolly pine in the Piedmont of South Carolina, with comparisons for the 25- and 35-year age classes[1]

Age	Specific gravity	Weight per cubic foot inside bark	
		Ovendry	Green
10	0.385	24.0	60.1
11	.391	24.4	60.0
12	.396	24.7	59.8
13	.400	25.0	59.7
14	.405	25.3	59.5
15	.409	25.5	59.3
25	.438	27.4	57.0
35	.458	28.6	54.6

[1] From a study by U.S. Plywood-Champion. (Adapted after Zobel et al., 1971.)

the tops of merchantable trees is useful, although it has low yields and other defects common to juvenile wood. Even though tracheid length is greater than for normal juvenile wood from the base of the tree, topwood, whole young trees, and juvenile wood of older trees gave very similar pulp (Barefoot et al., 1970; Ellwood et al., 1969). Because of the size and number of knots with their associated compression wood, a higher proportion of "abnormal" wood is found in topwood than in the lower portion of the merchantable bole. According to von Wedel et al. (1968), approximately 8% of the bole of young trees consists of knots and associated compression wood, whereas up to 14% was found in their tops (table 6). In older, open-grown trees with large limbs, knots and compression wood can be much more prevalent, approaching 40% or more of the topwood volume.

Specific gravity of topwood above the 4-inch merchantable diameter limit has been found to average 25 p.c.f. in 17-year-old slash pine in southwest Georgia (Collicott et al., 1968). Other studies have been summarized in table 7; although the specific gravity values fluctuate for the two species, they are all low. Generally the topwood portion of the tree normally used for pulpwood (near the 4-in.-diameter limit) has 10% to 15% less dry weight per cubic foot of green wood than does the basal portion of the tree.

As an illustration of the density of wood formed at the top of the tree compared to wood from basal bolts, one study on twenty-four 15-year-old trees in the Piedmont of the Carolinas by Catawba Timber Company showed the following:

Seventh Bolt		Basal Bolt		Weighted Whole Tree Value	
Specific gravity	Density (p.c.f.)	Specific gravity	Density (p.c.f.)	Specific gravity	Density (p.c.f.)
0.40	25.0	0.48	30.0	0.45	28.1

There is some question about how important topwood is, based upon how much of it is produced. For example, it was found that in a 12-year-old stand of slash pine the nonmerchantable topwood added about 5% to the total weight harvested, whereas in 17-year-old trees this dropped to 4% (Collicott et al., 1968).

Other Wood Qualities

Abundant data are available for a number of wood properties of young trees for characteristics other than specific gravity. However, emphasis in this paper has been on specific gravity, due to the overriding importance of cell wall thickness in determining yield and quality of pulp and paper (Barefoot et al., 1970). Therefore, only limited mention will be made of other wood qualities of young trees and how they relate to older trees.

Moisture content can be calculated on the basis of dry weight, green weight, or volume. We have chosen dry weight (which can be easily converted to green weight, appendix table 4, Zobel et al., 1968) because it indicates the weight of water present per unit dry weight of wood. For example, a moisture percent of 137

Table 6.--Knotwood and associated compression wood in the last merchantable bolt (to a 4-in. top) and the bolts above and below this position in young loblolly pine[1]

	Knot volume	Compression wood volume	Knot plus compression wood
	Pct.	Pct.	Pct.
1 bolt below	2.3	8.9	11.2
Last 4-inch bolt	2.3	9.5	11.8
1st bolt above	2.6	11.5	14.1

[1]After von Wedel et al., 1967.

Table 7.--Generalized wood density of the "nonmerchantable" wood above a 4-inch top for loblolly and slash pines[1]

Group	Specific gravity	Density	Number of trees sampled
		P.c.f.	
Loblolly pine			
Young trees	0.36	22.5	130
Older trees	.42	26.2	109
Slash pine			
Young trees	.40	25.0	170
Older trees	.37	23.1	36

[1]Adapted from Zcbel et al., 1971.

(based on dry weight) indicates that there is 1.37 pounds of water associated with every pound of dry wood. Moisture content and specific gravity are usually inversely related, a fact of great importance when logs are bought by green weight (Zobel et al., 1968). This is illustrated by the subtotals in table 8.

Moisture content is especially important when buying wood from young trees. In industry the opinion is sometimes expressed that a fair transaction has taken place when wood is purchased by green weight. But young trees have more moisture than do older ones and often there is a large disparity of actual wood due to age. Comparison of an 18-year-old stand with a 30-year-old stand in the same area is shown in table 9.

There is a similar trend with tree size; a cord of 6-inch DBH trees had 1,680 pounds of dry wood compared to 2,200 pounds per cord of 10-inch trees. The total green weight of a cord of the 6-inch and 10-inch trees were quite similar despite the greater actual wood volume in cords from larger diameter bolts; the 520-pound difference in dry weight was offset by greater moisture content in the wood of smaller (younger) trees.

Moisture content increases from base to top of tree and is greater in juvenile than in mature wood, as illustrated in table 10. Tracheids are short in young trees (see table 9), averaging 2.5 to 3.0 millimeters in trees younger than 15 years compared to 3.5 to 4.5 millimeters for 30-year-old trees. Based on 340 loblolly pines 5 years of age in South Carolina, the average tracheid length was 2.27 millimeters whereas 11-year-old trees in the same area averaged 2.85 millimeters. Such length differences have an effect on paper properties, especially when combined with the thin cell walls found in wood of young trees. The trend for short tracheids in juvenile wood is the same for loblolly and slash pine, as shown below (also see table 11).

	Tracheid Lengths	
	Juvenile wood (Mm.)	Mature wood (Mm.)
Loblolly	2.56	[illegible].41
Slash pine	2.60	3.50

In a study of 581 loblolly pines in the South Carolina Coastal Plain, tracheid length was 4.5 millimeters for the 30th ring and 3.50 for the seventh ring; for Piedmont trees, tracheid length for the seventh ring averaged 3.26 millimeters. An important point is that tracheid length varies by mother tree families, as does specific gravity and moisture content, and can differ as much as 0.5 millimeter, giving opportunity for improving tracheid lengths if such is desired (table 8).

Cell wall thickness and cell diameter vary by tree age and location within the tree. Note the values of the 11-year-old trees as compared to topwood from mature trees and mature wood of mature trees (table 11). The young trees and topwood have similar specific gravity but topwood has longer cells with thicker cell walls.

Table 8.--Wood properties of 11-year-old loblolly pine trees grown in south Georgia[1]

Family	Specific gravity	Moisture content	Tracheid length
1	0.41	137	3.04
2	.40	138	3.16
3	.40	141	3.00
4	.40	152	2.60
5	.40	159	2.77
6	.39	145	2.77
7	.39	140	2.90
8	.39	155	2.92
9	.39	147	2.76
10	.39	145	2.70
Sub-Av.	.40	146	2.86
67	.36	165	2.95
68	.36	151	2.91
69	.35	179	2.93
70	.35	170	2.82
71	.35	184	2.73
72	.35	181	2.67
73	.35	181	2.91
74	.35	185	2.93
75	.35	187	2.75
76	.35	192	2.79
Sub-Av.	.35	178	2.84

[1]The study (from the Cooperative Heritability Study with International Paper Company) is based on 380 trees from 75 families. Only the 20 families with the highest and lowest specific gravities are shown in the table. Relationship of specific gravity with moisture content and lack of relationship with tracheid length are illustrated, along with inherent family differences.

Table 9.--Green and dry weight of loblolly pine 18 and 30 years of age[1]

Age	Green weight per 100 cubic feet	Dry weight per 100 cubic feet
Yr.		
18	6,230	2,696
30	5,880	2,759

[1]After Zobel et al., 1971.

Table 10.--Moisture content of 25 15-year-old loblolly pine by juvenile and mature wood and bolt location

Bolt No.	Juvenile wood moisture content	Mature wood moisture content
	Pct.	Pct.
1 (base of tree)	103	97
2	125	116
3	134	121
4	139	129
5	145	134
6	149	137
7	149	143
8 (top of tree)	178	--

Table 11.--Wood qualities of 11-year-old loblolly pine compared to older trees and topwood of mature trees[1]

Wood property	11-year-old trees	Mature trees[2] (topwood only)	Mature trees[3] (merchantable wood)
Specific gravity	0.42	0.41	0.48
Density (p.c.f.)	26.2	25.6	30.0
Tracheid length (mm.)	2.98	3.59	4.28
Cell wall thickness (microns)	3.88	6.72	8.04
Lumen size (microns)	42.25	32.47	32.78
Cell diameter (microns)	50.01	45.91	48.86

[1]From 36 11-year-old trees, International Paper Company, 6 trees for topwood and 16 trees for mature wood from the study by Ellwood et al. (1969).

[2]Average for the top 4 5-foot bolts, with a mean diameter of 5 in.

[3]Juvenile wood excluded.

In general, based on many studies, tracheid lengths of mature trees average about 1.5 millimeters longer than for young trees, wall thickness about 3 microns greater, lumen diameter about 5 microns less, and overall cell diameter about the same (Zobel et al., 1961). The major factors that will affect the final product are the wall thickness and cell length; cell length is important for only certain products while wall thickness is important in nearly all products.

Utilization of Young Wood

A number of studies on the utility of young wood and topwood in southern pines have been made by the pulp and paper industries; similar tests have been made in other species (Bublitz, 1971). Unfortunately, most of them are classified and thus results cannot be directly cited in this paper. Since there appears to be a general pattern, however, broad trends can be discussed.

The lower pulp yields of young wood and higher costs of harvesting small trees are very important economic considerations and their effect is felt from the stump to the final paper product. Approximately 2,000 pounds of dry wood were obtained per cord from 15-year-old loblolly pine trees, while 2,400 pounds were obtained from 25-year-old trees; a similar trend is evident in pulp yields from younger trees. Additional economic considerations are that trees that averaged only 5 inches in diameter cost nearly $10 per cord more to harvest than did those 10 inches in diameter; 0.1 more cords per hour could be harvested per man from 10-inch rather than 5-inch DBH trees. One specific laboratory kraft pulping study made by Hammermill Paper Company on 12-year-old plantation-grown loblolly pine in central Alabama well illustrates the wood and pulp and paper qualities of young trees as affected by specific gravity as well as their relationship to the normal mill timber supply (table 12).

The pulping and bleaching conditions and chemical applications based on wood were identical for all four cases, producing very similar degrees of cooking and bleaching. The differences in moisture content, yield based on dry wood, and specific gravity were used to calculate comparative yield of pulp based both on green weight and green volume. If one assumes that a mill is limited in production by its digester volume, which is frequently the case, then pulp production rates should be proportional to yield per green wood volume, as shown in table 12. Manufacturing costs other than raw material costs would vary inversely with the production rate. The cost of cooking and bleaching chemicals per ton of pulp would increase very slightly for juvenile wood because of slightly lower yields based on dry wood.

Physical properties related more specifically to development of fiber-to-fiber bonding (mullen, tensile, fold) tend to be higher for juvenile than for mature wood. Within the juvenile wood classes these properties are higher for the lower density samples because of the greater conformability of the thin-walled fibers. As expected, tear, which depends heavily on fiber length and fiber strength, and opacity and caliper, both of which depend on fiber stiffness, all show behavior trends opposite to the bonding properties just mentioned. It should be noted that the extreme high-density juvenile wood, although denser than mature wood, does not measure up (or down) to mature wood in physical properties of the resultant pulp.

Table 12.--Wood and pulp characteristics and yields from pulping high-, intermediate-, and low-density juvenile loblolly pine wood, compared with mill-run chips[1]

	Mill chips	Juvenile wood		
		Low density[1]	Average density[1]	High density[1]
Specific gravity	0.44	0.365	0.419	0.477
Moisture, pct. of dry wood	119	142	119	112
K number	27.5	26.5	28.3	28.4
Rejects, pct. of dry wood	0.45	0.23	0.19	0.42
Crude yield, pct. of dry wood	47.5	44.2	45.7	47.1
Crude yield pct. of wet wood	21.7	18.3	20.9	22.2
Pounds pulp per cu. ft. green wood	13.0	10.0	11.9	14.0
Estimated mill production, pct. of normal	100	76	91	107
Bleached brightness	88.6	88.0	89.3	88.3
C.E.D. viscosity, cp.	22.4	29.2	30.0	25.8
At 750 ml. Schopper-Riegler[2] freeness:				
Tensile, Kg./in.	15.01	16.88	16.80	15.87
Mullen (burst)	60	73	69	70
Tear, g.	120	88	96	109
Fold, M I.T.	1,540	2,390	2,150	1,970
Opacity	67.3	62.0	62.0	64.2
Caliper	5.8	5.1	5.4	5.4

[1]Based on 6 trees in each of the density classes.

[2]Pulp beaten in Valley beater tests on 75 g./m.^{2} sheets.

It was concluded from this study that juvenile wood will produce a pulp considerably different from mature wood, but whether it is better or worse depends on the intended product. In any case, a cost penalty is imposed. It is also obvious that considerable potential exists for improvement of juvenile wood pulps if genetic or cultural manipulation can significantly alter its specific gravity.

From the preceding study and others, some conclusions can be drawn regarding pulping juvenile wood. It can be compared to older trees as follows:

1. Gross yields are from 10% to 15% less per unit volume or unit green weight compared to older trees. Additionally, cellulose yields will be less. Gladstone et al. (1970) states, "A reduction of rotation age in loblolly pine will increase the proportion of juvenile wood received in the mill. Pulping of wood produced at low rotation ages will result not only in well-documented losses of yield per unit volume of dry wood, but also in losses per unit weight of dry wood. It is estimated that the latter yield loss could be as high as 1.2% on a pulp basis for a reduction in rotation ages from 30 to 20 years." Yields will drop more drastically as lower ages of harvestability are approached; magnitude of possible effects is shown in table 12.

2. Mullen (burst) and fold of paper from young trees is good because of better bonding, but tearing strength is lower than from older trees. Opacity is lower than from standard pulp; paper smoothness is good from juvenile wood, with high apparent density.

3. The consumption of chemical per ton of pulp is increased slightly and about a 10% increase in other manufacturing costs is realized. Maximum production is curtailed if digester capacity is limiting.

4. More tall oil and turpentine per cord will be obtained from older trees, especially after heartwood formation has started.

5. With some manufacturing adjustments, pulp from young trees is usable for many products made from regular pine. Its use results in marginal strengths for some and in exceptionally good properties for others.

It is fortunate that pulp and paper from young trees do have utility because the supply of such wood is increasing at a rapid rate. When a mill uses 5% to 10% juvenile wood, little attention is paid to it; but when it approaches 50%, as it has in several mills in the South, utility of fibers from young, fast-grown pines becomes of major importance. With adjustments in cooking and manufacturing processes, quality of paper and yields can be considerably enhanced over that reported in some early studies where standard cooks and manufacturing methods were used.

There has been a reluctance in the pulp and paper industry to segregate and use young wood to its best advantage. Until the basic differences between young and old wood and pulp qualities are known and corrected, serious and costly errors will continue to be made. In one mill, for example, it was found that wood from young thinnings was undesirable for the product manufactured. So rather than pulping the young and old wood separately and then blending the fibers to produce

a desired paper, the chips were blended together and pulped together. The resultant mixture made satisfactory paper but at a loss of efficiency and high cost; it was like cooking steaks from a yearling and from an old bull in the same oven and expecting both of them to come out done to a turn. If young wood is to be handled in large volume we now know enough of its fiber and pulping characteristics to warrant special handling if any semblance of efficiency is to be obtained. In many parts of the Southeast it will be those mills that learn to use young wood to its fullest, exploiting its advantages and minimizing its disadvantages, that will prosper.

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Gordon--You talked about some of those papers for which the juvenile wood is wonderful. Would you just give us a little bit of further detail on that and tell us what a few of those are?

Zobel--I'll turn to an expert who knows all the answers.

Lawrence, Champion Papers--I'm supposed to make these comments on the panel a little later. But in brief, these are the same type of papers that George Sheets mentioned yesterday--mainly thin papers, business form papers, papers for coating, which need a flat surface and good formation. Very roughly, I would say printing publication business form papers are the ones this type of fiber is ideally suited for.

Dawson, Forest Service--In your trees ages 3 to 5 for those 3,300 trees sampled, approximately how great was the range in the specific gravity and in the pounds per cubic foot?

Zobel--That's a real good question. When your trees are younger, the range is relatively small; as they get older, the range spreads out. But we did this for 50 some families and found a range, from family to family, of 5 pounds per cubic foot in 3-year-old material. So already at that young stage some families are very high and some are very low.

Larson, Forest Service--Do the trees with high juvenile specific gravity tend to be located in any particular region, or were they well scattered?

Zobel--They were completely scattered at random. You never know when you're going to find one and you can't predict it.

Bensend, Iowa State--Did you use proximity to the living crown at the time the wood was formed to make this identification of juvenile wood?

Zobel--Oh, definitely not. We picked trees that were well pruned and other trees that were open grown, and the open-grown trees do not continue to produce juvenile wood. They go about to 10 years, then slip over into mature wood. There is a relationship; certainly juvenile wood is formed in relation to the crown. But it won't continue forever. The number of rings from the pith is a key thing here. I don't know whether it is an aging process or what, but the tree just doesn't continue to produce juvenile wood. Yesterday somebody mentioned that, when you put fertilizer on, it extends the juvenile period. We're finding the same thing. It tends to extend the juvenile period but it isn't because the crown is there. Often we put fertilizer on trees after the crown has been shed, and we see the crown in the top of the tree and no side branches.

Berklund, Nekoosa Edwards--From what you said, some of the southern mills may be in for some trouble in the future with the pressure on short rotations. Now looking way into the future, what is the answer? Is this to accept the lower yield using these woods which are forced maybe by higher taxes, sufficiency in logging and planting, etc?

Zobel--The lower yields may not be so low if they change the manufacturing process for the kind of wood that is coming in. In one mill I know, half of their furnish this year came from 11-, 12-, and 13-year-old plantations. We can grow these things very rapidly. For one company, we grew trees 10 to 14 inches in diameter in 10 years and harvested them.

Isebrands, Forest Service--You mentioned that certain families have better characteristics than others. Do you look into the possibility that some families have higher incidence of reaction wood?

Zobel--Yes, and I think there is a very definite relationship. Some families tend to have a lot of reaction wood or compression wood, others have a little bit. But one family where the tree is leaning a little bit produces a lot of reaction wood, and another family where the tree is leaning a great deal essentially produces no reaction wood. So the response to this physical force which produces reaction wood is quite different from family to family. We found a rather high heritability of compression wood formation.

Bengtson, TVA--Bruce, I hope I misunderstood you when you said that you didn't think the crown was involved in the fertilizer response and in wood quality. In my experience, I don't think there has ever been a case where there was a response to fertilizers where there was not an obvious effect on the crown. This was not necessarily a lengthening of the crown, but certainly there was an effect on it.

Zobel--You misunderstood me. What I said is that, when we fertilize, it doesn't make the tree hold its crown down. It prunes off naturally. Certainly there is an effect on crown; it greens up, thickens up, and all this.

Hearon, Boise Cascade--You mentioned that you had no carryover from father to son on the high-density juvenile wood. Then why do some of the trees have high-density juvenile wood?

Zobel--No, we have a great carryover from father to son. That's what I was trying to show on one of these tables. The high-gravity fathers and mothers produce high-gravity children, so to speak. So we do have a group theory. It is rather strongly controlled genetically.

Hearon--Well, why do some trees have high-density children and some trees don't?

Zobel--I don't know, they grow just intermixed. Of course, I'm a geneticist so you know what my explanation would be. But anything that you do to change the growth pattern of a tree is going to change the root. And so you can't just say it's due to genetics because some trees grow in slightly different environments that have an effect. But the parentage is very important.

Burkhart, SFA--Is there a possibility that the high gravity juvenile wood has a higher percentage of latewood than the lower gravity juvenile wood?

Zobel--Yes, definitely it does. You can see it visually. I didn't measure but when you take the sample it immediately hits you that here is juvenile wood with big broad bands of summerwood.

Burkhart--And this evidently then is a genetic characteristic?

Zobel--Oh, definitely.

THE THREE-RINGS-PER-INCH DENSE SOUTHERN PINE--SHOULD IT BE DEVELOPED?

by

PETER KOCH[1]

Abstract

The three-rings-per-inch dense southern pine could be utilized for many of the purposes to which present-day timber is put. Difficulties might be encountered in uses where strength is important, and some product specifications would have to be revised. Until such a tree can be developed the following objective is proposed for southern pine silviculturists: Over large areas, grow the maximum possible dry tonnage per acre per year, and grow it on the fewest possible straight stems of uniform size, taper, and spacing.

* * *

The southern pines are the most important group of softwood timber species in the United States. Further, their importance is increasing. It is estimated that by the year 2000, 51% of the softwood used in this country will come from the South. These pines occupy about 20% of the 509 million acres of commercial forest land in the United States.

Currently, southern pineries furnish raw material for about 15% of the softwood plywood manufactured in the United States, 23% of the particleboard, 25% of the softwood lumber, 36% of the fiberboard, almost 40% of the market dissolving pulp, 41% of the groundwood pulp, a major share of the kraft pulp, over 75% of the poles, and nearly 100% of the turpentine and rosin.

Some of the commodities are also important in international markets. In 1968 the kraft mills of the South produced approximately 25% of the total pulps and 45% of the kraft pulps required in the world; the southern pines provided wood for about 77% of this pulp. They additionally supply about one-half the world's naval stores and three-fourths of the crude tall oil produced outside the Sino-Soviet bloc.

Since the southern pines are a major source of wood products in the United States, it is useful to consider the rate at which they grow and to assess the effects that accelerated growth might have on their utilization. In the opinion of many foresters, the bulk of the southern pine lands are capable of growing in excess of a cord per acre annually. Through genetic selection and intensive cultivation, yields in some plantations will likely be substantially increased by the year 2000--perhaps to three cords per acre or even more. Under favorable conditions, such as those found in certain parts of South Africa, Swaziland, Australia, New Zealand, and

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Brazil, loblolly and slash pine plantations have produced as much as five cords per acre per year during the initial rotation.

Six rings per inch is perhaps a fairly usual growth rate for southern pine in the United States today. Let us then inquire into the effect on utilization were this growth rate to be doubled so that wood of the future would average only three rings per inch, with growth so regulated that ring width would be constant at one-third inch from pith to ring 30. Further, let us assume that such fast-grown wood will occur in a range of specific gravities from about 0.4 to 0.6 (basis of green volume and ovendry weight), just as it does now. Under this assumption, entire stems would average about 0.5 in gravity; but diameter inside bark would be 6.7 inches at age 10 years, 13.3 inches at 20 years, and 20 inches at 30 years.

The following discussion briefly summarizes the likely effects of such growth rate and specific gravity on the properties of poles, timbers, lumber, laminated wood, plywood, particleboard, fiberboard, and pulp and paper. It omits any consideration of the economic effect that would result from doubling wood production by harvesting two crops of trees during the time span now required for a single crop. Obviously, though, many patterns of distribution would be altered by such a twofold expansion in volume.

Poles

Ready availability under standardized grading rules, straightness, little taper, high strength, absence of damaging spiral grain, and ease of drying and treating, all contribute to the widespread use of southern pine poles in the United States. Most southern pine utility poles are sold in length classes from 30 to 50 feet; diameters at the butt, therefore, generally range from about 9 to 20 inches. At three rings per inch, such poles would show 14 to 30 rings at the butt.

Pole specifications are published by the American Standards Association; poles are grouped into classes according to the load (applied laterally at the top) required to break them. The specifications require that the outer wood zone at the butt must show at least six rings per inch, although poles having four rings per inch are acceptable if they contain 50% or more latewood. Obviously, the grading rules would require revision if poles with three rings per inch were to be marketed.

Although the straightness and taper of southern pine stems should not be adversely affected by rapid growth, it is likely that fast-grown small poles would have inferior strength. For example, a 30-foot class 9 pole measuring about 7 inches in diameter at the butt would show only 10 or 11 growth rings; such a pole would be comprised almost entirely of juvenile wood and would, therefore, be relatively weak. Poles 14 inches and larger in diameter would show more than 20 rings at the butt; if the mature outer wood had at least 50% latewood, such poles should have adequate strength.

No data are published that correlate grain spirality with rings per inch; in this country the outer wood of fast-grown southern pines appears to have little spiral grain. The effect of ring width on the permeability of the wood is also in doubt,

but the data so far available indicate that wood showing three rings per inch can be dried and treated readily. Fast-grown southern pines in pole sizes contain less heartwood, and should therefore be more easily treated, than slow-grown trees of the same diameter.

Timbers

By current rules of the Southern Pine Inspection Bureau, timbers for structural use (i.e., stress-rated) must average on one end or the other not less than four annual rings per inch. Use of timbers showing only three rings per inch would require revision of this specification. If latewood content could be maintained at 50% or more, fast-grown wood should be usable in most structures. Many timbers contain boxed heart, however; such pieces, if 7 inches square or smaller, would contain virtually no wood older than 10 years and, therefore, could not be expected to show a high latewood content.

Like poles, timbers having three rings per inch should be easily treated; boring and machining should not be unduly difficult.

Lumber

Southern pine wood finds wide use as nonstress-rated framing, structural, and finish lumber. For most framing purposes that do not require stress-rated lumber, fast-grown wood can serve adequately. Under present grading rules, however, wood having less than four rings per inch is excluded from the important structural grade of No. 1 Common dimension lumber. It is possible that these rules could be revised to permit inclusion of faster grown wood having a sufficient percentage of latewood. For structural lumber, the wide rings in themselves become objectionable only if earlywood is placed so that it is highly stressed or in such a manner that mechanical connectors rely only on earlywood for holding power. Compression wood can be particularly damaging, however, in boards or planks showing only a few rings.

Users of clear finish lumber prefer slow-grown wood. Lumber with three rings per inch has a bold look that most consumers find somewhat objectionable. Fast-grown wood is difficult to machine into complex patterns (e.g., finger joints), and wide bands of latewood receive nails with difficulty and are prone to split. When painted, fast-grown dense southern pine frequently develops raised grain that is visible through the coating; moreover, paint retention is notably poor.

Because of the widespread adoption of the chipping headrig in the South, a significant portion of all southern pine lumber is now cut from logs measuring 7 to 12 inches in diameter. Larger logs are converted into veneer for plywood, and smaller logs are chipped for pulp. Since fast-grown logs 7 to 12 inches in diameter show only 10 to 18 rings, it is evident that much of the lumber will contain pith-associated wood. Such wood may warp excessively unless it is dried under mechanical restraint.

Not all uses for southern pine are best served by slow-grown wood, however. For example, steam bending is best accomplished with fast-grown, low-density wood. As another example, wooden boxes are most easily nailed if the wood has wide rings and is low in density.

Laminated Wood

Systems have been developed for placing wood in laminated beams so that the strongest wood is in the outermost, most highly stressed laminae. These systems permit complete utilization of batches of lumber of variable strength. If selective placement of laminae is to achieve maximum effect, however, a portion of the lumber should have a modulus of elasticity in excess of 3 million p.s.i., and a tensile strength of more than 10,000 p.s.i. Such high strength values are infrequently reported for lumber showing only three rings per inch.

Plywood

Southern pine veneer bolts must have a certain minimum density in order that the veneer cut from them will be comparable in strength to Douglas-fir veneer. If latewood content sufficient for this density is attainable in bolts showing three rings per inch, the veneer will display wide patches of latewood as well as wide patches of earlywood. Veneer from dense fast-grown bolts tends to be rougher, less uniform, and much more difficult to glue into plywood than veneer cut from slow-grown bolts. The gluing problems arise mainly because latewood-to-latewood bonds are difficult to achieve with normal spreads of phenol-formaldehyde resins.

In southern pine plywood given exterior exposure, face checking is most severe, delamination most rapid, and paint failures occur soonest if veneers are cut from fast-grown dense bolts.

Particleboard

Particleboard properties are strongly correlated with the density of wood from which the particles are derived; low-density wood is generally preferred. Board properties are also closely related to the specific surface of component particles (i.e., surface area per unit weight) and with the variation in specific surface among particles. Fast-grown dense wood yields particles with a very wide range in specific surface. It is likely, however, that manufacturers would find no serious problems in producing board from wood with three rings per inch; most would prefer wood averaging 0.4 specific gravity over wood of 0.5 gravity.

Fiberboard

McMillin[2] has shown the effects of gross wood characteristics on properties of fiberboards made from loblolly pine refiner groundwood. With high-density boards, stress at proportional limit in bending and modulus of elasticity were positively correlated with rings per inch, i.e., fast-grown wood yielded somewhat weaker boards. Also, medium- and high-density boards from fast-grown wood had less dimensional stability parallel to the surface than boards from slow-grown wood; for medium-density board only, fast-grown wood yielded boards with less dimensional stability perpendicular to the grain.

McMillin concluded that most of the fiberboard properties he measured were improved by use of fibers refined from dense wood containing a low percentage of latewood. He forced stratification of samples from the core, middle, and outer portions of the tree stem so that wood of high and low specific gravity and of slow and fast growth was considered at each position. Because of this forced stratification, the correlation between latewood content and unextracted specific gravity was low ($R^2 = 0.66$) as compared to that in entire stems. Thus, proportion of latewood exhibited a range of values at all levels of chip specific gravity.

The data showed that fiber prepared from corewood of high unextracted specific gravity yielded boards of superior strength. Dense veneer cores therefore would appear to be a desirable raw material from a strength standpoint. In contrast, fiber refined from slabs and edgings of low density would be expected to yield boards of inferior strength.

Pulp and Paper

The large body of literature relating pulp properties to fiber morphology leaves me with the impression, perhaps oversimplified, that pulp and paper makers will continue to use southern pine wood in whatever form it is grown as long as it is available in uniform, large quantities, and at a reasonable price. In short, three-rings-per-inch, dense southern pine would probably be acceptable to most manufacturers. In 1971, most pulp company foresters appear to be primarily concerned with growing the maximum possible dry tonnage of wood per acre per year.

Discussion

A major objective of the Southern Forest Experiment Station's utilization project in Pineville, La., is stated as follows:

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[2] McMillin, C. W. Fiberboards from loblolly pine refiner groundwood: Effects of gross wood characteristics and board density. Forest Prod. J. 18(8): 51-59. 1968.

"By 1980 to invent processes that will double the 1963 product tonnage economically recoverable from each southern pine tree."

This objective is probably attainable.

One might frame an equally specific objective for geneticists and silviculturists working on intensive plantation culture of southern pine:

"To develop seed sources and silvicultural techniques that will yield plantations of southern pine trees averaging three rings per inch and 0.5 specific gravity (on the basis of green volume and ovendry weight, unextracted)."

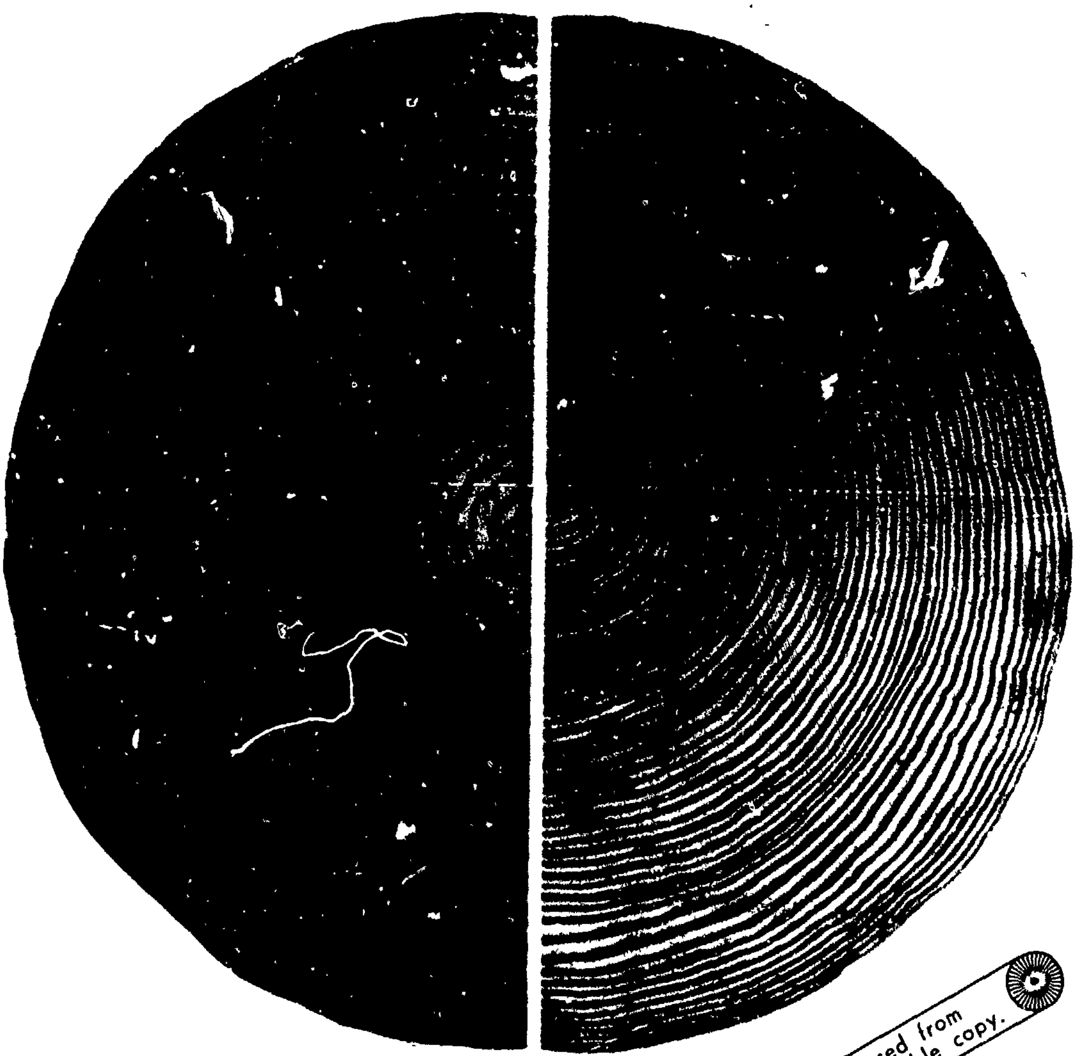
From the preceding text it is evident that this objective is debatable in forests managed for solid wood products. In part, choice of objective must rest on this country's requirements for poles, timbers, lumber, laminated wood, plywood, particleboard, fiberboard, and pulp and paper. Since many economists forecast an increasing demand for timber products, as well as a decreasing land base from which wood can be harvested, it is my opinion that geneticists and silviculturists should press forward vigorously to develop southern pine plantations in which stems average 0.5 in specific gravity and show a uniform ring width of one-third inch from pith through ring 30. Even the most optimistic geneticist will probably concede that attainment of this goal will require numerous generations of tree breeding in addition to much basic research on manipulation of ring width and density.

Until the three-rings-per-inch, dense southern pine tree is a reality, I propose an interim, and more general, objective for southern geneticists and silviculturists:

"Over large areas, grow the maximum possible dry tonnage per acre per year, and grow it on the fewest possible straight stems of uniform size, taper, and spacing."

This interim objective would do more than increase the tonnage of pine production. Since uniformly spaced, large straight stems of equal size and taper can be logged and processed more readily than smaller crooked stems of random size, taper, and spacing, the cost of conversion would be reduced and the competitive position of pine wood would be enhanced.

The interim objective is applicable equally to unthinned stands grown on short rotations for pulpwood and to thinned plantations managed for longer rotations to yield saw logs and veneer bolts. In both cases, stands would be manipulated primarily to yield high tonnages, but with recognition that harvesting and processing costs are positively correlated with the number of stems per acre.



Comparison of three- and six-rings-per-inch growth rates. Cross sections are from moderately dense loblolly pine logs with fairly uniform ring spacing from pith to bark. The section at left shows 31 rings and that at right 57. Both logs measured 20 inches in diameter inside bark.

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MacKinnon, Crown Zellerbach--Is there a possibility that, with stress drying, we can get some chip-n-saw material out of the first or second thinnings in the interim system?

Koch--Yes, we are pushing ahead and investing a lot of money in an attempt to commercialize a continuous dryer that operates on a high-temperature restraint system. From our experiments we get virtually 100% straight wood out of that system. Whether we can make it commercially, I don't know, but we're going to try.

Gordon--We have a few minutes so I wonder if anyone would like to comment with regard to any of the papers this morning?

Bromley, American Pulpwood Association--Most of the papers presented seem to dismiss the possible impact of site or soil productivity. Does this mean that soil productivity does not have an impact on these wood characteristics, and if it doesn't, has this been dismissed scientifically? Because this isn't brought out. Are the 6- and 10-inch trees that were just compared from the same site? Or could this be really a difference between site conditions? Any of you who have been presenting papers can answer this question, I suppose, as to why site seems not to be covered in these discussions.

Zobel--We never take trees from different sites. They're always on the same site, the same stocking, the same age. But we've made extensive studies with International Paper Company and four or five others. Within the normal site range, say between 75- and 85-foot sites, there is very little effect on wood and the effect of stocking is very little. These have been not only investigated widely, but they have been sort of dismissed. If you go from a 60-foot to a 120-foot site, definitely there is an effect, but within normal operations the effect on wood is very little from site to site or with normal stocking. If you go to 8 by 8, 8 by 10, or 10 by 10 there is no effect on wood properties. Now if you go from a 3 by 3 to a 12 by 12, there is an effect.

Burkhart, SFA--We've done a considerable amount of work on the effect of environmental manipulations on the ratios of holocellulose and alphacellulose to lignin. We do find there is a decided effect on these ratios due to site characteristics or between suppressed trees and dominant trees on the same site. It can amount to as much as 4% or 5% ratio of alphacellulose or holocellulose to lignin. So there is an effect of site, at least in Texas. Some of the studies that we're doing seem to indicate that some of this can be alleviated by manipulation of the site.

?????--Which site conditions give you the better alphacellulose percentage? The better sites, the more moist sites, or what conditions?

Burkhart--No, it's just the opposite. The dry sites and suppressed conditions give the higher ratios of alphacellulose and holocellulose to lignin than under the better conditions. We have a couple of projects going that may give us an indication of why, but it's too early to say.

Thor, University of Tennessee--I'm glad this matter of site was brought up. I think we have ignored it to a large extent. Personally, I've worked with site effects on the wood properties of one hardwood and two pine. Contrary to some opinions expressed, I do find some fairly decent relationships. This is up to something like 20% to 30% of variation in the important characteristics like specific gravity or tracheid or fiber length, or whatever it is. The reason so little work is done in this field is that it is difficult to quantify what you are observing; maybe you worked with 15 to 20 different soil and site characteristics. Most of these data are not parametric and do not have normal distribution. When you try to analyze it, you seem to violate every statistical principle, and so it is a very tricky thing to do. Maybe this is the main reason that so little is done with it--it is too frustrating to try to analyze it afterwards and make biological sense out of it. You can pick up a few things, for example, a trend towards somewhat higher specific gravity with better moisture-holding capacity over the site. When you take these data and try to treat them so you can forecast what samples would do on another site, it doesn't work at all. It is not a very promising thing to pursue if you want to keep your sanity.

SUMMARY

Gordon--We're going to have a brief summary of the symposium at this time presented by Dr. Carl Ostrom, presently Director of Timber Management Research for the U.S. Forest Service in Washington, D.C. He received his B.S. from Penn State and his M.S. and Ph. D. from Yale University. His career in the Forest Service began at the Rocky Mountain Forest Experiment Station, and from there to the Southeastern Station, to his present position as Director of Timber Management Research in the U.S. Forest Service. Dr. Ostrom, it's a pleasure to have you here to bring this summary to us.

SYMPOSIUM SUMMARY: EFFECT OF GROWTH ACCELERATION ON WOOD PROPERTIES

by

CARL E. OSTROM[1]

Although all of the papers in this symposium relate to the effect of growth acceleration on wood properties, they deal more specifically with the following three questions:

1. What are the special properties of juvenile wood and topwood in southern pine?

2. What are the effects of fertilization, thinning, and irrigation on the wood of important softwoods and hardwoods?

3. What is the relation of wood structure to pulping characteristics and to the quality of paper and solid wood products?

Properties of Juvenile Wood and Topwood

Zobel, Kellison, and Kirk have effectively presented the reasons why we may be faced with utilizing more and more juvenile wood and topwood whether we like it or not. These reasons relate not only to the great increase in softwood plantations in the tropics and subtropics, but also to the public pressure to reduce forest residues.

Juvenile wood of loblolly and slash pines has lower specific gravity, higher moisture content, shorter tracheids, greater cell lumen diameter, and thinner cell walls than mature wood. It yields less cellulose, and produces papers with greater bursting strength and fold, but lower tearing strength and opacity. Juvenile wood produces a lower yield of extractive and is more costly to process. Use of juvenile wood results in marginal strength for some paper products, but in very good properties for others.

Topwood has a higher moisture content, longer tracheids, and more knots and compression wood than juvenile wood in the bole.

Breeding trees to produce juvenile wood with properties more like those of mature wood is a distinct possibility in view of the degree of natural variation among progeny groups in wood characteristics and in their gradient within the bole.

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Effects of Fertilization, Thinning, and Irrigation

In the studies reported here, fertilization, thinning, or irrigation in various combinations usually increased growth rate, provided that one of the other factors involved (nutrients, growing space, or moisture) was not limiting. Single treatments were generally much less effective than combinations of fertilization with thinning or irrigation.

The overall effect of growth-acceleration treatments in pines was to halt or reverse the normal decline in growth rate and the normal increase in wood specific gravity toward the outside of the bole. In order to detect these trend reversals, one should have data for the periods before and after treatment for treated and untreated trees.

For the period after treatment only, softwoods having accelerated growth generally had more earlywood and lower specific gravity. In Douglas-fir, the density of earlywood increased and that of the latewood decreased, resulting in more uniformity within the ring.

In second-growth ponderosa pine, the natural trend toward more uniform density of wood with advancing age was reversed by thinning, with or without fertilization. The X-ray technique was very effective in revealing density distribution within and among rings.

In spruce pine, the most consistent features of wood of fast-growing trees were greater tracheid diameter, larger proportion of thin-walled earlywood fibers, and lower specific gravity (9%) than in slow-growing trees of the same age.

Spiral grain, which tends to be greater in juvenile wood, was less in irrigated than nonirrigated young slash pine.

In second-growth Douglas-fir, Siddiqui and coworkers got a 3% higher yield of pulp (wood basis) from fertilized than from unfertilized trees, which helped to offset 10% lower wood specific gravity.

Tracheid length was relatively unaffected by growth acceleration in conifers, but in sycamore and aspen fiber length was somewhat greater in thinned or irrigated trees than in controls.

Fertilization had no effect on wood density in young sycamore and aspen, but fertilization plus irrigation resulted in reduced wood density of aspen. In older trees of furniture woods, Mitchell observed a slight increase in wood density associated with an increase in growth rate from fertilization.

Growth acceleration did not affect the proportion of different cell types in the wood of aspen or sycamore.

Relation of Wood Structure to Properties of the Product

Horn's study of 12 western conifers indicated that the denser woods make papers that are lower in elasticity, bursting strength, and tensile strength. Increased fibril angle provides more stretch in the paper. Horn proposed the use of a ratio of fiber length to wall thickness that is positively correlated with elasticity and tensile strength.

Barefoot and coworkers with loblolly pine found that denser wood provides greater tear strength and bulk, but lower burst and tensile strength, as in Horn's work with the western softwoods. Pulp yields were positively correlated with percentage of latewood. The original tracheid length in the trees had only a secondary effect to that of the associated cell wall thickness or specific gravity of the wood.

Mitchell reported no adverse effect of fertilization on properties that affect pulping in red oak, yellow-poplar, and white ash.

Only two papers dealt with the relation of growth acceleration to the properties of solid wood products. Fertilization which accelerated growth in red oak, yellow-poplar, and white ash had no effect on their machining properties. Koch poses the possibility of maintaining a growth rate of three rings per inch in southern pine on a 30-year rotation. He concludes that these fast-grown pines with wide bands of earlywood and latewood would have the following attributes:

1. Low paint retention and poor gluing characteristics.

2. Reduced machinability and reduced attractiveness for clear finish lumber.

3. Probably inadequate strength if harvested early for small poles or small squared timbers.

4. Adequate strength for large members.

5. Good steam bending.

He concludes that this growth rate objective is debatable in forests managed for solid wood products.

Recommendations

From among the conference papers, the following recommendations emerge:

The differences in wood characteristics and processing costs that result from growing conditions are great enough to warrant adjustments in forest management practice.

The most effective adjustment is to grow softwoods to an age that will subordinate the proportion of juvenile wood, except for special types of papers for which juvenile wood is superior.

Cultural treatments that accelerate growth rate will tend in the softwoods to halt the normal trend toward denser wood in the older rings.

Relative uniformity of wood properties over the life span of the tree is highly desirable for most uses and should be one of the objectives of the timber management regime.

On very deficient soils, the deficient nutrient should be supplied promptly, and the response in growth rate should greatly overshadow measurable effects on wood properties.

More attention should be given to sampling of specific gravity as well as moisture content of the raw material. Juvenile and older wood should be sorted when feasible (for example, when they arrive as veneer cores or as slabs and edgings).

Present knowledge of natural variation and inheritance of wood characteristics suggests that breeding for the control of wood density and related properties will be successful.

One recommended objective that considers all products is to manage southern pines in a way that will maximize the dry tonnage per acre on the fewest number of uniform stems of high quality. This seems like a desirable objective provided it results in a rotation long enough to reduce conversion costs in the woods and in the mill and to guarantee the tree sizes and wood properties needed for the intended use.

Relation of Growth Acceleration to National Objectives

There are two further aspects of growth acceleration that relate to long-range national objectives. The first is the viewpoint that forest culture or silviculture is concerned with the growing of forests for any combination of uses. This viewpoint is essential on public lands and highly desirable on private lands. Fortunately, the techniques that provide growth acceleration can also be applied in ways that will enhance other forest values such as wildlife. This is especially true of stand density control through thinning. The point is that growth acceleration practices may have effects on other resource values that could considerably exceed their effects on wood properties.

A second long-range objective of intensive culture should be to meet a higher proportion of future product needs on the best timber-growing lands. In this way we can offset the trend to take other forest lands out of production because of high scenic and recreational values, or because of environmental impacts of harvesting on unstable soils, shallow soils, or other sensitive areas.

This does not mean that timber-growing should be pulled out of areas where it is a desirable part of multiresource management, for careful timber removal is the one operation through which more wildlife, watershed, range, and recreation objectives can be accomplished than through any other single treatment. But the pressures for timber harvest in unsuitable or questionable situations can be greatly reduced by growth acceleration on the most productive lands. Thus we can help to solve on our best timber lands some of the severe environmental problems we are encountering elsewhere. This whole spectrum of problems is well served by your research on the nature of wood produced by growth acceleration in productive forest areas.

PANEL DISCUSSION

Gordon--This morning's program will be concluded with a panel discussion on the impact of accelerated growth to the pulp and paper maker. I'd like to introduce those members of the panel who have not participated before and, therefore, I will skip over Harold Mitchell and Bruce Zobel and introduce the other four members.

First is Monty Hearon who received his B.S. and M.S. in chemistry from the University of Denver and his Ph. D. from MIT. Following that in his career he worked in research and development in cellulose esters with Eastman Kodak and for a number of years with Crown Zellerbach where he was in research and development and also in chemical products derivation. Additionally he was an assistant professor at MIT, recently he has been in consulting, and currently he is with the Boise Cascade Corporation where he is assistant to the senior vice president.

Phalti Lawrence is a native of North Carolina and a graduate of North Carolina State University in chemical engineering. He's been associated with Champion Papers, now U.S. Ply-Champion, for 4 years in various technical functions, most of these in research and development. Presently he is research associate and manager of pulp and paper making research and development for Champion at Hamilton, Ohio.

Hans van Buijtenen is a native of Holland. He received his B.S. degree at the Agricultural College, his M.S. degree from the University of California at Berkeley, and his Ph. D. degree from Texas A&M. His first work after receiving his Ph. D. was at the Institute of Paper Chemistry and then followed a number of assignments, including work at the Northeastern Forest Experiment Station. At present he is with the Texas Forest Service at Texas A&M where he is in charge of the tree improvement program.

Bob Zahner is at the School of Natural Resources at the University of Michigan. Bob received his Ph. D. in 1953 from Duke University. From 1953-59 he was at the Southern Forest Experiment Station and I see a note here that Harold Mitchell hired him. While there he was in research in tree, soil, and water relationships; since then he has served as professor of forest botany at the University of Michigan from 1959 to the present. In teaching and in research he's been involved with tree physiology and forest ecology, especially in wood formation of pine and upland hardwood.

Gentlemen, we will turn the discussion of this over to you. Harold Mitchell will be the spokesman and chairman of our panel.

Mitchell--The panel's job is to attempt to come up with some conclusions in regard to what we know and what we don't know, where the weak spots are, what kind of research is needed in the future, and pinpoint this sort of thing. Each panel member, except me, is prepared to make a 5-minute presentation expressing their views on this subject. Let's start with Dr. Hearon.

HEARON--I'm an organic chemist and as a forester I probably planted about two trees in my life; the few in my backyard don't look very well. So, having established my credentials as a nonauthority on growing trees well, I'll plunge fearlessly ahead and tell you how to grow them. Seems to me that growing trees is, in a sense,

like growing annual crops. You need sunshine but there isn't very much you can do about that other than plant your trees in the right location. Trees need nutrients and the largest nutrient as far as I know is carbon dioxide; we're providing this by being alive and by driving two or three automobiles per family, so that's all right. The other nutrients are these so-called fertilizers--nitrogen, phosphorous, potassium, magnesium, calcium, boron, zinc, and iron. Then there is water. In Portland we don't really have a water problem because it rains all the time during the winter. Finally, and in a sense the most important, is what kind of tree you have. I don't mean necessarily the species, but rather the tree that is going to grow fast or big, and be good or bad from the point of view of the kind of wood it makes. So it looks as if a number of things can be done to improve the growth of trees.

In the papers that were given, I was a little surprised there were few statements about how the fertilization was done. It seems to me that it could be extremely important whether the fertilizer is put on from the air, sprinkled on the ground, or as a liquid sprayed on trees, and whether it is a slow-release fertilizer or a fast-release fertilizer. I suspect little was said about that, partly because of lack of time to go into those details. But I'm not sure that you can correlate these things unless you know exactly how the fertilization was done.

Another point that occurred to me was that little was said about the condition of the soil, as far as nutrients are concerned, before you fertilize. If the soil already is loaded with these various nutrients, I would suspect that additional nutrients are not going to do very much good. On the other hand, if they're very scarce in these, the effect would be quite noticeable. Work done in the forestry department in some of my previous associations would indicate that fertilization was beneficial only if there was a deficiency of these nutrients in the soil; they always tested the soil before they started putting on fertilizer. It would also seem to me that condition of the ground would be extremely important because the plants with shallow roots would take up a nutrient, perhaps preferentially, from the trees. But often this was not mentioned as a factor.

Now I realize that these problems are extremely complex and thus research on them is very difficult. You have unknown factors and many of them are difficult to control, so the only way in which you can really get results that are meaningful is take very large replications of trees. If you try to analyze on a single tree or on a few, you can come to probably erroneous conclusions.

As far as the economics of fertilization are concerned, it seems to me that the biggest problem is trying to figure out the value of pulpwood in 20 or 25 years. You can figure out pretty well the material cost for putting on fertilizer or irrigating; you can get the labor costs, and so forth. But what will be the value of that wood when you harvest it? In making any kind of economic analysis, you should be very sure of the present value of the analysis because you're putting the money on doing the work today and you won't get it back for 20 or 25 years. And the value of that money 20 or 25 years from now is going to be a lot less than it looks like on paper.

From the point of view of the papermaker, I'm inclined to agree that if you give a papermaker a reasonably satisfactory raw material, and keep it uniform, he has the tools and the knowledge to use it. He has many, many things he can control--

the pulping, bleaching, refining, operation of the paper machine, what additives are used, and what mechanical devices are employed to modify the paper. All of these things give the papermaker a lot of latitude in the kind of properties he can get out of his final product from a fairly wide variation in raw material. There are many, many examples of this. As George Sheets pointed out, if you were going to pick the ideal wood, I suppose Canadian black spruce would be perfect. On the other hand, when people started using western hemlock out on the west coast, they didn't think it would be any good at all. Today they think it's great. They first thought they couldn't possibly use Douglas-fir with those big, stiff fibers. Today there is more Douglas-fir pulp than anything else on the west coast. And so it goes. We learn as we go along. Given a reasonable raw material, I have a lot of confidence the papermaker and the pulpman will be able to utilize it.

Finally, to me the most important area for further work is in changing the kind of trees we are going to grow. I only hope we'll have a little time later to discuss this aspect.

Mitchell--Thank you. As soon as we have the formal presentations up here, we're going to throw open the discussion. Now so we don't get all industry viewpoints, I will next call on Dr. van Buijtenen.

VAN BUIJTENEN--Thank you. My interest in this subject stems from my interest in tree improvement. It comes from several angles, including pine tree improvement, where we are establishing about 350 acres of seed orchard. We're also very much involved in hardwoods, working with five or six different species. And probably more than anything else is a project of the TAPPI Forest Biology Committee that I've been involved with for the last couple of years. We're trying to evaluate the whole process using a systems approach. We start with the pollen grain and end with the finished product. Of course, we can take it only one product at a time, following a case study approach. What we're trying to see is where genetics can be affected and what the economics would be. We also need to know what role intensive silviculture could play and what the role of the mill is. Should we continue to just grow wood anyway we can and let them worry about what to do with it, or should we try to grow wood they would be reasonably happy with?

In considering some of the bigger gaps in the information we need, I think one was pointed out by Gene Shoulders yesterday. That is, how well can we size up the future? By and large, we assume that our present objectives are going to hold about 40 to 50 years. This, of course, may not be true at all. The future is going to be different than it is now and it is going to be different from the way we think it is going to be. I think the one crucial question is where we are now on this exponential curve; we may be at the portion that's curving, where the change is increasing, or we may be fairly well on our way on the straight-line portion already. But somewhere along the line we're going to hit the leveling-off point. I don't believe things can keep changing as fast as they have.

All of us in research have to set priorities and we work on a very narrow section usually. We see only our own specialty. This is why systems approach is so important--to put the information we have into one overall picture. Some of the things we are doing may not be relevant to the overall picture and we may be leaving big holes in other places.

How do handsheet properties relate to pulpmill-run paper? As far as I can tell, nobody has a good handle on it. Most of our research data are based on handsheet properties. How do you translate this into the quality of machine-run paper? Then, what is the value of quality? If your quality changes up or down, how can you put a dollar value on that? We have some approaches to solving this, but there just is really very little information around.

Mitchell--Thank you. Next I think I'll call on Dr. Zahner.

ZAHNER--Thank you, Mitch. Whether or not we like to grow trees bigger and faster is no longer a question. We are doing it, and foresters all over this country are pretty well facing up to this challenge. I've been going to soil science and other kinds of meetings for the last 20 years and it seems that 75% to 90% of the papers have to do with how to accelerate growth. It takes a symposium like this to evaluate what this accelerated growth is doing for wood properties and for the forest industry.

In combination with fertilizer, water often becomes very important. In fact, fertilizer is usually useless on dry sites without water. But the practical importance of irrigating large areas may not be apparent for perhaps the next 30 years. In fact we probably will see less availability of water in the sense of irrigation for accelerating growth. We might just be using the forest as a filter to get rid of effluents--but not increasing growth. But I don't think we are going to use irrigation to increase yield of a crop on any very large scale in this country. It is interesting academically to see the influence of irrigation on wood properties, but I don't believ that we're going to get into this on our upland sites in large areas.

The one accelerating treatment that does have promise is fertilizers. And we've already proved that, in certain sites on the wet acid soils of the southeastern coastal plains where phosphorous becomes limiting, a very inexpensive treatment will give us a two- and three-fold increase in growth. It turns a nonproductive site into a productive one. In the Pacific Northwest you can increase the Douglas-fir productivity 15% to 20% by applications of fertilizer on certain sites at certain ages. I believe that the coming decades will see a large, judicial use of fertilizers on an applied scale. If the forest manager can increase growth by 15% by using fertilizers on say a 5-year rotation, this can become a practical and economical thing to do. We are not, however, going to dump fertilizers on all of our soils all over this country. A great many soils will not respond to fertilizers; a few soils will respond very well; and a wide range of soils between may or may not respond economically. Soil surveys will come into more use as we get into widespread use of fertilizers.

Mitchell--Thank you, Bob. Next I'll call on Dr. Lawrence. He's always good for some fine comments.

LAWRENCE--I'd like to talk about the desires of the paper industry as to the types of fibers. I know that Bruce Zobel and some of our other friends have been frustrated by their inability to get a simple, clean-cut definition of what we want in the way of fibers. We haven't been evasive, we just don't know for sure. Because conditions change, the paper industry has learned to use what is available. I think our papermakers sometimes surprise themselves by overcoming handicaps or adapting available fibers to the needs and the products.

There are two very general types of papers made, which I would distinguish for this discussion as the brown papers and the white papers. In general, the brown papers are the linerboards, the bag krafts, and those types which essentially require strength and, for competitive reasons, economy of manufacture. They are generally much thicker than the white papers. The white papers are generally business and production papers and they require some characteristics utterly unimportant in most brown papers. For one thing, they are generally much thinner. Uses of white papers, particularly in publications, require that they be of lighter weight as postage rates go up. Even though the weight is decreased, the customer expects the strength and the opacity to be maintained at the prevailing level.

Some things unique in the white paper category, which do not bother the maker of the brown papers a great deal, are uniformity, flatness, smoothness, and opacity. You want all the strength you can get, but it's not as critical as it is with brown papers. But these other characteristics are very important.

Formation or uniformity is a particularly critical factor in white papers, and is influenced strongly by fiber length. The tendency to form clots or clumps in the papermaking process varies roughly as the cube of the fiber length. A long fiber may be disadvantageous or objectionable in making many grades of white papers. In some of our own productions, we have on occasion limited the percent input of slabwood chips simply because they have longer fiber lengths and give formation problems. Thinner walls and, generally speaking, narrower fibers and more fibers per gram, help meet the qualification requirements of white papers.

I'm dwelling on this because our production is almost entirely white papers. So we're perhaps more conscious than average of some of these requirements. These differences do not need be tremendously great to effect an improvement.

Some time back we made a study comparing slow-growth and fast-growth loblolly pine. The differences were altogether the result of natural growth. We used nine samples representing a spread from 5 to 12 inches in diameter, 12 to 49 years in age, and growth rate from 2 to 10 rings per inch. Our results were not unlike some that have been reported. Only a couple of things showed up as being statistically significant in correlating with growth rate. One was the shorter fiber length, like a reduction from 2.5 to 2.1 average length for all tracheids present including short and broken tracheids. Another statistically significant factor was a reduced tearing strength with increased growth rate. Other correlations which showed up but did not quite qualify as being significant were lower wall thickness (reduction from 5.3 to 4.3 microns), a reduction in the length-width ratio (65 to 45), and an increase in the width-to-wall thickness ratio (8 to 10-1/2). We did not happen to get the L/T ratio which was discussed yesterday. There was no significant correlation with growth rate, fiber width, percent springwood, pulp yield, wood density, or viscosity. Now these characteristics I've just mentioned are in the wrong direction for the most part for brown papers, but they are in the desired direction for making white papers. So perhaps you can understand why sometimes you get seemingly contradictory answers in interpretation because different people have different objectives.

One final comment on the economic side. This discussion for the past 2 days has been extremely interesting but somewhere along the line we have a joint responsibility to reduce it to fairly simple terms, such as how much is it going to cost us per

acre or per ton of wood produced, and what benefits in turn will we realize from this. Indications are that the benefits will more than offset the penalties where fertilization is considered or justified. But I think we're going to have to get some hard numbers on which to implement programs that we've been talking about.

Mitchell--I have saved Bruce till last because you can always depend on him to stir things up and to provoke some audience questions and participation.

ZOBEL--I'm going to take a radical and somewhat overpositive position, because you never get action unless you do. And I'm going to talk only on southern pine pulpwood application for mill use. Now anything we do to change the growing conditions of trees is going to change the wood! Some of you misunderstood when I answered Bill Bromley about the effect of site. What I had answered is, in small site changes we have not found a major effect on wood. But we're bedding and doing very intensive site preparation. No one knows what this is doing to the wood. We have a big study going with Brunswick Pulp and Paper Company now. They have 16 years of studies on different kinds of site preparation and we're working with them to find out what does this do to wood and wood properties.

I don't think we're talking about fast growth at all in this symposium. I think we're talking about the use of young wood. Even if you want to believe there is a relationship between fast growth and wood properties, this is minor compared to the effects you get when you're forced into using younger wood. This trend for using younger wood is definitely in the industry. In the center of the tree you have wide rings. In the center of the tree you have low specific gravity. But that doesn't mean that wide rings make low specific gravity. And this is the sort of thinking many people have had. And it is at the base of a lot of overemphasis on fast growth. Fast growth is important because we can harvest the trees younger. This to me is the real key point.

Now when I first came to the South I found a publication that showed the specific gravity of loblolly was 0.43, for slash it was 0.52, and for longleaf it was 0.56. And our companies were using this to decide which species to plant. But when I looked at the results, the loblolly had been 12 years old, the slash 22, and the longleaf 40 years old. If you compare these trees at the same age, the differences are very, very minor. We've done this on a large scale and these species differences just don't exist. So what do our companies do? They plant large acreages of slash pine out of the range with the feeling that, because it's high density in north Florida, it's going to be high density when grown in North Carolina sandhills. It isn't. It's no higher density in the sandhills than loblolly grown in the sandhills. This kind of thinking has created quite a lot of difficulty in the industry.

I do want to comment about the future. A number of our companies, particularly Continental Can, has stressed that the future in forestry is not in growing fibers, it is in growing cellulose. Many of us feel that we're going to be working with reconstituted cellulose, and the fiber form in which it occurs is really not very important. With companies like Continental Can the whole push is to get the maximum tons of cellulose per acre and not pay much attention to the exact form in which it comes, whether in thick walls or thin walls or whatever. Now maybe this is wild but that's the way I feel about the future trend.

The question came up about getting both good growth and good specific gravity. Yes we can get both; if we're careful we can breed strains that are both fast growing and of high specific gravity. It requires some care, because if you're careless you might improve one to the detriment of the other. We have a monograph that is coming out from this heritability study with International Paper Company, covering 10 or 12 years of intensive basic research. In that work we found that the two important things to increase tonnage yield per acre are height growth (the best indicator of volume improvement) and specific gravity. And these two characteristics should be emphasized if you're trying to improve tonnage yield per acre.

Now one last blast on growth. Don't get mesmerized by the statisticians. We did a study in Texas, a very extensive one on the effect of growth rate on specific gravity. The results were based on several thousand trees. The correlation was negative, the <u>r</u> value was -0.15, it had three beautiful little stars up there meaning that it was statistically significant. But what does it mean? It just means that 2-1/2% of the specific gravity is accounted for or related to growth rate, and there's 97-1/2% floating around that you have to work with. What difference does it make if the relationship isn't big enough to have some real value?

<u>Mitchell</u>--Thank you, Bruce. Now did that provoke some discussion out there?

<u>Staebler,</u> Weyerhaeuser--Until the panel talked, I thought there had been too much reference to present-day technology. Everything is referenced to what we know and what we can do now and then this related to accelerated growth. A number of people on the panel brought out the shortsightedness of looking at only present-day conditions. One of my bosses prods me and tells me that it is not enough to look alone at change, you must also look at the change in change. In considering that, I decided this conference <u>might</u> have been held at the Forest Products Lab 20 or 25 years ago. And we might have been addressing exactly the same question that we're talking about at this symposium. Paper No. I could have been called the "Possibilities for Removing Bark from Slabwood to Permit Conversion to Chips," and that might have been given by Peter Koch's father. And the second paper would be "Can the Southern Pinery Support a Kraft Paper Industry?" and we would have brought in somebody from the Forest Service to give that paper. And this is not really a joke because I took forest economics under Sam Dana at the University of Michigan in 1939 and at that time we were discussing whether the South could support a sixth kraft pulpmill. The next paper on this program 20 or 25 years ago could have been "How Can We Use Wood With Six Rings Per Inch?" and you, Mitch, might have given that one yourself. And the last paper to cap it all would be "The End of Virgin Southern Pine Is In Sight--Will There Be A Use For Second-Growth?" And that would have been given by Bruce Zobel's dad.

<u>Mitchell</u>--Who's next?

<u>Koch</u>--I'm a little concerned that there isn't more emphasis on the solid wood uses of southern pine. As we look through the southern pine region today we can't escape the fact that veneer is more valuable than lumber and lumber is more valuable than chips. And it seems to me that companies enjoying the most competitive positions are those who divert those portions of the tree to their highest value. Conclusions that might be applicable to pulp companies are not necessarily applicable to people who divert parts of the tree to their highest use. We don't know about the change in the future, but it seems likely that veneer will continue to be more valuable than lumber, and lumber will continue to be more valuable than pulp chips.

Hildebrand--Mead Corporation--I would like to know more on the many conditions that exist--site conditions, site quality, etc.--the variables are so great. Do we know enough answers to fertilize on a commercial scale? Some companies are at this already.

Mitchell--The question is, what variables affect growth, how do we evaluate them, and determine fertilizer needs? Speaking from my own experience on hardwoods, I think we can determine from foliar analysis whether or not there are deficiencies of phosphorous, potassium, or nitrogen, not the rare elements. We have done enough to know what the level, say of nitrogen, should be in the leaves in the working range. We've tried that out in a number of places. For instance, we put in some fertilized plots on a natural stand of black walnut in southwest Wisconsin. And we did leaf analysis on these trees. In one case the trees were growing in a cove site, on deep rich soil. There the leaf analysis showed that the nitrogen content of those particular trees was quite high and it would be doubtful if they would benefit by nitrogen. On another site where the soil was thinner and poorer, the nitrogen content of leaves was down in the area of 1.5%. You could predict ahead of time about how much more nitrogen this second area needed. Then we went ahead and put it on and proved our point. On the poorest site, we got a tremendous stimulation on the growth rate of walnut. Now whether this is economically feasible or not, let me give you some perspective. Walnut sells for about $800 a thousand in 1-inch boards right now. When you can double the diameter growth rate of an 8-inch walnut tree, you're making money. Even if you had to spend $10 a tree to put it on, you couldn't miss.

Zahner--I'd like to relate this to what Bruce Zobel said. I think that accelerated growth in the future does mean young growth--maximizing biomass production per acre. This will be done with very short rotations, close spacing, and these kinds of things that foresters are working with now to accelerate growth. And fertilizers will be added if necessary. There are literally thousands of papers on the subject to cover most species, most ages of species, and most soils in the country. I think the science is far enough along today that I can say, yes, we do have some pretty good recommendations in things that are going to be used immediately and in the near future. I would like to call on George Bengston who is a superexpert.

Bengston--I think your summary was excellent, Bob. I think there are two provinces in the United States where, if I were betting my own money on fertilization, I'd be quite happy to do it. These are the acid soils of the lower coastal plain of the southeastern United States where responses to phosphate fertilization are quite consistent. Researchers mainly at the University of Florida have developed a system of predicting on a basis of both soil and tissue tests whether a soil is responsive to phosphate fertilization or not. I don't think that there is any chance that a person can go wrong in applying phosphate fertilizers to these sites. By the same token, I don't think we've reached the point of maximum efficiency of fertilization on these sites. In the Pacific Northwest on Douglas-fir there is a bit more room for questioning as to the best sites to fertilize, but the responses are sufficiently consistent and the means of diagnosing the deficiencies are sufficiently good that we are going to go forward at a fairly rapid clip. But there is a lot of middle ground. The folks in North Carolina are beginning to work intensively on the piedmont sites, but there's a question about economic feasibility of fertilizing in these areas. Soils are responsive but the economics are questionable.

I think we're going forward at a fairly rapid clip. Probably within 10 years or so we can say with reasonable assurity that response will be economically feasible in other areas.

It must be recognized that perhaps there is a difference in what is economically feasible on industry lands and what is economically feasible on the lands of private owners. It has been pointed out in Sweden and by some pulp and paper company people in this country that, if one is operating on a sustained yield basis and can predict that fertilizers will increase the yield by say 10%, one can go ahead then and cut an additional 10% and recover his money from fertilization immediately without having to stick on the business of compound interest. The private landowner doesn't have this advantage.

Mitchell--We're supposed to arrive at some conclusions here. So I'm going to try some myself and see if we can get some unanimity of opinion. I would conclude from everything that has been said that more and more fertilizer is going to be used in this country to stimulate the growth of forest trees on sites that research has shown will have an adequate response to sufficiently cover the cost and justify the application. This presumes research will have been done to guide such applications. It presumes also that either soil analysis or foliar analysis shows which element is deficient and you that have a good idea of how much is needed to achieve the necessary results. That's something I could conclude from what's been said here. Anybody want to argue with it?

Zahner--We must be prepared for adverse comment, or at least some resistance, from environmentalists on the overuse of chemicals on forest land. A lot of pressure is now being brought upon agricultural uses of chemical fertilizers. Perhaps some of you know that Illinois State legislature is now considering a bill to restrict the use of nitrate fertilizers in agricultural lands because they feel these fertilizers are being overused and are getting into the waters. I think we are on safer ground because forests are good systems to lock up any nutrients that are added. The nutrients stay in the cycle, on the site, and are included in the productivity of the site. Now certainly the applications will not be annual, probably 5- or 10-year intervals. The forest ecosystem is an excellent place because of the organic matter that is present and because of the rapid uptake of nutrients to lock these on the site and keep them in the system and cycling and being used in the biomass production. If we are careful and don't go overboard, we'll be safe from the criticisms of people who believe that we shouln't use fertilizers on forest lands.

Mitchell--In the first presentation by Dr. Hearon, he asked what's happening to the underbrush and undercover and a nice thought occurred to me. On those fertilized plots at Black Rock Forest, about a month after they were fertilized, I remember the ground cover was luxurious. The dogwood blossomed all over the place from the added nitrogen. A few weeks later I noticed that all the deer in the Hudson Highlands seemed to be gnawing on these fertilized plots. And they were so attracted to this lush vegetation that they gnawed every plot down to nothing. The plots were square and the borders looked as straight as a chalk line. Anything outside the plot that wasn't fertilized, the deer wouldn't touch, but everything in was gnawed right down to the ground. Now something attracted them to that. So when you fertilize you also fatten wildlife and make them more prolific and everything, and that's another good reason to fertilize.

van Buijtenen--I am happy to see that Bruce agrees that we are going to have wood that will be lighter and have shorter fibers, unless we do something about it by breeding. I do believe that the quality difference may be a whole lot more important than Bruce was indicating. Out of the TAPPI study it looks as if, even for a simple product like linerboard, the cost involved in compensating for quality losses or the potential gain that you can get for gain in quality are of the same order of magnitude. They are of the same order of magnitude as the kind of gains we get in dollar terms, in volume, and in yield differences. This means two things. It means when everything is working for us, like it would be in the case of white papers, we get an extra bonus. When things start running against us, we really have to watch our P's and Q's so we don't wipe out all we are gaining in yields by a loss in quality. We just can't blindly start increasing yield without paying attention to quality.

I think we have almost come to the end of the line as far as the usefulness of surveying the different trees within a species or different species is concerned. To get any further, we will probably have to go to mathematical models or synthetic models of paper. I think some of this has been done. There is a very good model for tear factor; for instance, I think the tensile strength is not as good. It is the kind of thing I think can be done, although it may be quite difficult to do. But to get any further we have to get a much more fundamental understanding of rating properties of a sheet of paper.

?????--I have a comment on the fertilization area. Two points perhaps haven't been brought up. On timing, obviously, trees respond differently at different stages of growth. If you were considering short-rotation harvesting at 15 or 18 years, and you knew you had response for 5 years after fertilization, there are some obvious times when you could apply your fertilizer, get your beneficial effects, and get your money back in a hurry.

Also, there is considerable difference between species and within species, and hybrids respond differently than some of the parents. So there is a possibility of genetic improvement.

?????--I think we have pretty well covered irrigation and fertilization. I wonder whether a new symposium couldn't be held sometime on genetic development as related to quality. I would suspect that would be a 2-day discussion.

Hearon--When we talk about genetics we are often talking about going out and picking the seeds from the largest trees, growing those, and picking the seeds from the largest trees and growing those. This is an important activity and a good approach. But to me it is not a real basic genetic study. There is relatively little work done to try to get mutants of trees that would have some good properties for lumber, plywood, or papermaking. You could take seeds and try to change them by ultraviolet radiation, or treatment with dimethyl-sulfate, or something else. But the point is to try to make changes that could be reproduced and come out with some beneficial effect. When you change the genetic code you don't know whether you are going to get something better or worse. But you are going to get some kind of a change. This is long-range research. It isn't the kind that industry people like to do for several reasons, one of them being that they will never end up in any kind of proprietary position. So this kind of research is either going to have to be done

by academic institutions supported by industry, through one of the industry-supported organizations, or by the Government. It's going to be expensive and it's going to be slow. But I think in the long run this is going to pay off conceivably more than simply growing more trees per acre and using juvenile wood. If you wanted to dream a little bit, suppose you are able to change the genetic code so you could grow trees that had 6% to 8% lignin in them. You could tear down all the smelly kraft mills, run that stuff through a steaming defibrator, and right through the bleach plant. This would be a tremendous impact on the paper industry. Or suppose you could end up with a wood that had a 75% alpha-cellulose content. These are tremendous things that could be done and I think relatively little work is being done in this area.

Mitchell--Quite a bit of the kind of research you are asking for is going on. Maybe the reason you haven't heard much about it is that it hasn't been eminently successful. But quite a bit of it is in progress in Government and in the universities.

Auchter, FPL--First, you said the papermaker didn't specify what properties he wants. I think this is correct, not necessarily because he doesn't know but because he's afraid he'll be charged too much money if he spells out what fiber he wants. Secondly, correlation of handsheet properties to paper properties. I'm sure that any papermaker here will say that, for his own operation, he can correlate handsheet properties to the paper that come off of his machine.

The third item, Hans, is about trying to create a mathematical model without using fundamental properties. You're talking about tear. What is tear? Can you describe it to me? How many things go into a tear property? What is burst? How many things go into burst property? As long as the paper industry continues working with the multitude of empirical tests you aren't going to develop a mathematical model. So my cohort over there has been working for some years on fundamental properties of paper structure, which are much more important than the things you're trying to solve with a mathematical model.

Mitchell--I'm having trouble getting very specific conclusions. I'm getting a lot of comments and good ideas from which we may be able to distill some conclusions later on but maybe this isn't what Gus wanted. Would it be fair to conclude from the papers that were presented here, and especially Carl Ostrom's summary, that the fertilizer work reported had no horrible effects on wood properties that would lead us to question the whole idea of growth acceleration? Would that be a fair statement? I have seen no data that would discourage me from using fertilizer properly.

?????--I agree. I think that foresters, soil scientists, and fertilizer technicians have got the green light in terms of going on--at least for pulp and paper. Five companies are already doing it. So it's a sort of an accomplished fact, isn't it?

Mitchell--I would like to try another conclusion. So far as gaps in information are concerned I think there are weaknesses in research and information on hardwoods, on western conifers, and on trees for which the highest use is lumber, plywood, and other products, both hardwoods and softwoods. Now I know what the emphasis is in this symposium. But I think there is a dearth of information on the effect of fertilizer on hardwoods, especially hardwoods for lumber that goes into furniture,

hardwood plywood, millwork, and that sort of thing. I also think there's a dearth of information in research on western conifers. We had two good papers but, compared to southern pine, it seems that western conifers aren't getting much attention. And one recommendation might be that whoever is filthy rich, and doesn't know what to do with his money, get some of it behind research on these weak areas.

Crews, Colorado State University--I have a question here that at first glance may not relate to what we've been talking about, but in a long run it may. This has to do with nutrient depletion. At the Church hearings on clearcutting last summer, testimony was presented relating to nutrient depletion. And I think Mr. Bromley and Mr. Staebler will agree with me that the reaction to this testimony was eyebrow-raising to say the least. Following this testimony senators were throwing around words like "incredible," "amazing," "shocking." I would like to ask the people on the panel or people in this room about current research under way resulting from nutrient depletion.

Zahner--As briefly as I can summarize, everytime any crop is removed from any soil, there is a nutrient depletion. The agriculturists have been doing this for thousands and thousands of years. And there hasn't been the concern raised about nutrient depletion from agricultural use of land. With the future of growth acceleration, particularly young growth, and maximizing biomass production in short rotations, we're getting into the same category as agriculturists have been. I believe we can justify nutrient depletion on accelerated growth sites and plots and areas just as agriculturists do. We can justify the fact that the country required the fiber and, whether we are depleting the nutrients or not, this is the best way we have devised to furnish it. We add the nutrients back into the soil through artificial fertilization. This is an accepted agricultural practice and I think that we have to work on that same base here with accelerated growth. I believe that if we are careful in preserving aesthetic values, this question will not be raised again. Many of the problems that result from clearcutting are due to the logging practices and roadbuilding that result in soil slippage, erosion, and all these things. And these are probably more important than the nutrient losses. I believe we are on safe ground where we are going to grow wood rapidly. We're not going to grow this on scenic mountain slopes with frequent harvesting. I think we are going to grow our rapid-growing crops with short rotations and maximum biomass production in the flatter soils. Certainly, in the southeastern coastal plain, the question of nutrient depletion is not likely to be raised very seriously because the agricultural practices down there have been depleting the soil nutrients for hundreds of years.

Bromley--I'd like to accept Dr. Zahner's calm assurance that we don't have to worry about nutrient depletion but I'm still concerned. When I see sycamore or other species grown with successive generation, I hope that we are establishing some research to assure us on this point in the future. The experiences of your foresters definitely was that more culture will eventually deplete the soil. I don't know whether this is true, but this is what the records show. I feel that we should first of all go back to those records and find out whether there is really any basis in fact. And we should be able to put this thing to rest in the next generation of forestry. I'm sure you didn't mean that we shouldn't be studying this?

Zahner--No. It is an accepted fact that nutrients are depleted following the harvesting of any crops. The nutrient cycle is disrupted, and leaching takes a very strong loss of nutrients from any site from which the vegetation is harvested. These are well-known facts. Agronomists have accepted that for years and have worked around it by adding nutrients to replace those that leach away. There is a problem here, yes. But we have to approach it, much as agronomists have done, on a sustained yield basis of adding to the site to replace that lost both by leaching and by removing the crop. And this can be done in a number of ways--not only by adding artificial fertilizers but all sorts of organic matter. Maybe we can get rid of some of our sewage effluents, manures, and other things to help build the soil and keep it at a sustained level.

Mitchell--I'm sorry but I was instructed to stop this meeting because people have trains to catch, luncheon dates, and so forth. I want to thank the panel for their comments and the audience for all this fine discussion we've had. Thank you.

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FOREST PRODUCTS LABORATORY ATTENDEES

H. O. Fleischer, Director
J. F. Saeman, Associate Director
K. C. Compton, Technologist
M. A. Davidson, Writer-Editor

Division of Wood Quality Research

H. L. Mitchell, Chief
A. N. Foulger, Technologist
F. Freese, Statistician
R. R. Maeglin, Technologist
N. D. Nelson, Technologist
J. T. Quirk, Technologist
D. R. Schumann, Technologist
H. E. Wahlgren, Technologist
J. C. Ward, Technologist
K. E. Wolter, Plant Physiologist

Division of Wood Chemistry Research

H. Tarkow, Chief
D. F. Caulfield, Research Chemist
J. M. Harkin, Research Chemist
R. M. Rowell, Research Chemist
D. F. Zinkel, Research Chemist

Division of Wood Fiber Products Research

R. J. Auchter, Chief
V. L. Byrd, Technologist
W. F. Carr, Chemical Engineer
D. J. Fahey, Technologist
R. A. Horn, Technologist
J. F. Laundrie, Chemical Engineer
N. Sanyer, Chemist
V. C. Setterholm, Technologist

Division of Wood Engineering Research

B. A. Bendtsen, Technologist
R. L. Ethington, Technologist
A. J. Kass, Technologist